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EXPERIMENTAL L-BAND SST SATELLITE COMMUNICATIONS/SURVEILLANCE TERMINAL STUDY

VOLUME V

AIRCRAFT TERMINAL DEFINITION

by

Thomas K. Foley and Marvin W. Alnutt

November 1968

Prepared under Contract No. NAS 12-621 by

BOEING

COMMERCIAL AIRPLANE DIVISION

RENTON, WASHINGTON

for

Electronics Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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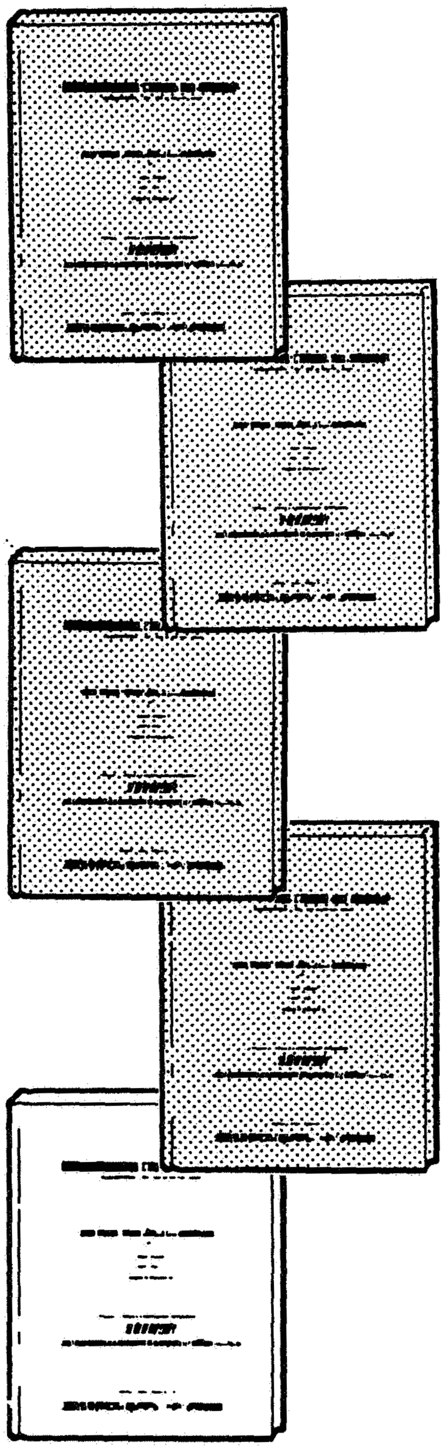

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The Boeing Company

SUMMARY

Specific aircraft terminal designs are developed, as part of NASA/ERC contract NAS 12-621, for both experimental and operational SST terminals for use in an L-band satellite communications/surveillance air traffic control (ATC) system. The designs are based on the requirements and analyses of the previous study documentation volumes. The terminal rf performance levels are defined for three postulated satellite alternate EIRP levels, nominally, 24 dBW, 35 to 40 dBW, and 50 dBW. The various terminal design tradeoffs are considered for each level, and a preferred experimental terminal design is selected to match the medium-EIRP capability, which is consistent with the potential capability of the ATS-F and G satellites.

Detailed functional descriptions, including block diagrams, are presented for the selected design. The hardware elements are chosen based on the results of an extensive equipment state-of-the-art survey of transmitter and receiver devices. The preferred design has the flexibility to demonstrate several test options, including (1) surveillance and/or single-channel voice operation with a low-gain hemispherical-coverage aircraft antenna and (2) multichannel voice operation and surveillance using a medium-gain (+3.5 to +8 dB) aircraft antenna. Test options also include the use of either a transistor (450° K noise temperature) or an uncooled paramp (attainable 50° K) preamplifier as a low-noise receiver front end. In addition, provision is made for evaluating both turnaround multiple-tone and BINOR surveillance concepts in the experimental program.

An operational terminal design is also presented predicated on expected 1975 satellite technology. The design is characterized by both surveillance and multichannel voice operation with a low-gain antenna system and a 50-watt solid-state power amplifier at the aircraft terminal. Consideration is also given to the requirements and constraints of the test program using the prototype SST and to interim experiments that could be conducted prior to the SST flight-test program.

1.0 INTRODUCTION

The purpose of this document is to develop the specific aircraft terminal design for both the experimental program and the operational system. The performance requirements imposed on the terminal design are those developed in the analysis contained in vol. II, "Operational Requirements Study;" in vol. III, "Communications/Surveillance Analysis;" and in vol. IV, "Antenna Studies." In addition, the design definition takes cognizance of inputs received during technical interchange meetings with the customer (NASA/ERC) and the system contractors (RCA and TRW).

The state of the art of the actual hardware is treated in Sec. 2.0. The development status of candidate hardware components is presented based on the results of an extensive state-of-the-art survey trip. The major manufacturers of airborne transmitters, power amplifiers, preamplifiers, and receivers were contacted to determine the availability of suitable L-band equipment or the development requirements necessary to produce the equipment. Data are presented to show performance levels, costs, and development status of the components. Recommendations are made for the component selection in the baseline design.

A functional description of the experimental SST terminal baseline design is given in Sec. 3.0. The performance requirements and operational constraints that the design must meet are described, and several major alternate designs meeting these requirements and constraints are discussed. The previous volumes of this report established what the specific parametric relations are, i.e., satellite EIRP vs. aircraft antenna gain and required transmitter power. The choice of satellite EIRP is an external decision factor that will influence both the experimental and operational aircraft terminal configuration. The NASA/ERC system contractors are currently studying this area. Therefore the impact on the aircraft terminal design of a high-EIRP (52 dBW), a medium-EIRP (35-40 dBW), and a low-EIRP (24 dBW) satellite is discussed in terms of antenna gain, transmitter power, and noise-figure requirements.

The terminal voice/surveillance modems are also discussed in terms of equipment and onboard data processing required for either a tone-ranging or BINOR-ranging modulation scheme. Detailed block diagrams are given to show how the surveillance, voice, and data signals are processed onboard the aircraft. Also included are the associated design factors of signal acquisition, timing, and synchronization, as well as operational constraints. The terminal interfaces are discussed and estimates of weight, power, and volume are presented.

Potential flight-test instrumentation is described in Sec. 4.0, since this instrumentation may be required in addition to the functional equipment for the experimental evaluation. The actual equipment needed would be defined in the phase III contract after establishing the specific flight-test plan. Also discussed are some experiments that could be conducted prior to the availability of the prototype SST.

The final section (Sec. 5.0) describes the growth of the experimental terminal into the operational configuration. This section considers design modifications including a potential reduction in aircraft antenna gain requirements. The latter is the result of anticipating a higher-EIRP satellite for the operational ATC system as compared to the expected lower-power experimental satellite (ATS-F or G).

A strong team effort was involved in conducting the overall study effort. The aircraft terminal definition reported in this volume was accomplished in close association with the analysis efforts of many people who contributed to the previous volumes. The following personnel made significant contributions to the terminal design effort:

Technical direction	T. K. Foley
Equipment state-of-the-art survey	D. Axe
Aircraft terminal functional description	B. J. Gaumond E. Sestak
Test instrumentation requirements	M. W. Alnutt

2.0 TERMINAL EQUIPMENT STATE OF THE ART

Throughout this program close contact was maintained with potential suppliers of L-band systems and components. Near the half-way point in the study program, the plants of 15 potential vendors were visited to determine their interest, capabilities, and previous research and development efforts in areas applicable to this study. In addition, 16 other companies were contacted by telephone regarding system or subsystem components applicable to this study. Most of the potential suppliers provided literature and product-description material, and many showed a very active interest in participating in both the experimental and operational portions of an L-band satellite communications and surveillance system.

Each potential vendor was given a short presentation of satellite communications/ surveillance techniques and projected terminal requirements as developed at the time of the survey trip. With the help of preliminary system power budgets, it had been determined that power-output levels from 50 to 1000 watts should be considered for terminal baseline studies. Manufacturers were accordingly asked to review their product lines for components meeting these power requirements as well as the frequency requirements of 1540 MHz to 1660 MHz. Toward the end of the survey, it was learned that the L-band assignment had been tentatively subassigned by the FAA, with uplinks at 1650 ± 10 MHz and downlinks at 1550 ± 10 MHz (ref. 1). The additional center-frequency and bandwidth information was used to better define which specific items of hardware would be suitable to the terminal design. The manufacturers were also asked to review the characteristics of receiver front-end devices they might have which exhibit noise figures below 5 dB to 6 dB. The manufacturers were told the environment would be approximately represented by MIL-E-5400 Class 2X. This requirement has since been relaxed to a MIL-E-5400 Class 1X environment since it was felt that a Class 1X environment (50 000 ft altitude, -54°C to +55°C temperature, forced-air cooling) better described the avionics rack area of commercial jet aircraft, including the SST.

In addition to supplying the technical characteristics of their devices, the component manufacturers were asked to provide cost-per-unit and budgetary pricing information, for small quantities of one to two units (experimental terminal) and larger quantities of from 100 to 500 units (operational terminals).

The first three of the following subsections describe those system and component characteristics collected during the survey that were pertinent to the L-band terminal. These subsections cover power-output devices and drivers, receiver front-ends, and transmission lines. In the fourth subsection the devices described in the previous three sections are further discussed, and certain approaches are recommended for optimum use in the L-band terminal.

2.1 Power-Output Devices

A survey was made of traveling-wave-tube (TWT), klystron, crossed-field, negative-grid, and solid-state device technology at 1600 MHz. As expected, since this portion of the frequency spectrum has been neglected in the past, there has been little development of applicable high-power cw devices. Nevertheless, a number of devices (primarily broadband TWT's) were found which met the power-output requirements of the preliminary terminal design. Device technology for electrostatically focused klystrons (ESFK) and crossed-field devices was found to be far enough advanced to support tube development programs aimed toward satisfying the operational-terminal requirements.

2.1.1 Traveling-wave tubes (TWT's).– Traveling-wave-tube amplifiers, available off the shelf, can provide cw power output levels of up to 1000 watts at 1650 MHz. Saturated gains of greater than 30 dB can be achieved. Bandwidth is no problem since the 20-MHz band centered at 1650 MHz can be easily spanned by TWT's. The salient characteristics of available TWT's are summarized in table 1.

Many of the existing TWT devices are heavy and quite large with respect to standard avionics components. Weights of off-the-shelf tubes vary from 8 to 21 pounds over the power-output range of from 100 to 1000 watts. The lengths of many tubes exceed the length of an Aeronautical Radio Inc. (ARINC) standard Air Transport Radio (ATR) long avionics package. The high weight attributable to TWT devices is primarily a result of the beam-focusing system required by the TWT. Two types of focusing are in use: solenoid and periodic permanent magnet (PPM). All present tubes operating above the 300-watt output level at 1650 MHz are solenoid focused–resulting in a much larger and heavier package than the tube itself. One manufacturer said PPM focusing could not be used with tubes operating above the 500-watt level. The length is a strong function of gain requirements. In general, tubes shown in table 1 average 20 inches in length regardless of power level. Diameters of from 3 to 4 inches are typical.

The major disadvantage of present TWT designs is their low dc-to-rf conversion efficiency. Typical efficiency for nondepressed-collector operation is from 14% to 15%; but, with a depressed collector, efficiency of from 20% to 25% is obtainable. Some of the off-the-shelf tubes do not have the collector electrically isolated from the remainder of the tube; therefore, depressed-collector operation is not possible. However, various manufacturers indicated that a modification to this characteristic during manufacture should not be too costly.

The quoted TWT efficiencies are based on typical broadband operation covering the frequency range of from 1 to 2 GHz. However, with narrowband requirements, it is possible to design a tube for operation at helix voltages higher than the synchronous value, thereby doubling beam efficiencies (ref. 2). The 100-watt S-band tube being developed by Watkins-Johnson (under contract to JPL) is a good example of this type of TWT (ref. 3). However, high-efficiency operation is accompanied by an increase in the amplitude of distortion products. The amplitude- to pulse-modulation conversion is increased three to five times over that of low-efficiency broadband tubes. Intermodulation products are also higher in the high-efficiency tubes. Fortunately, this becomes a severe problem only in tubes used for multiple-carrier operation and should not affect the terminal design. Harmonic output of the high-efficiency tubes is lower due to reduced gain at harmonic frequencies.

Most TWT suppliers felt that smaller tubes, tailored to the L-band terminal requirements, could be developed. As an example of the type of TWT that could be developed to meet the specific requirements, one of the TWT manufacturers was asked to provide a preliminary estimate of the electrical and physical characteristics of a TWT tube built to the following specifications:

Frequency .... 1640 to 1660 MHz, 1-dB points
Output power .... 500 watts
Gain .... $\geq$20 dB
Design goals .... Shortest length, highest efficiency

The following estimate of the tube's electrical and physical characteristics was provided:

Efficiency.	30 to 35%
Length	16 to 17 in.
Gain	20 to 30 dB
Developmental cost	\$10 000 to \$30 000

Based on cost data supplied at an earlier date by the same manufacturer, and upon cost data for the development of new power-output devices by other manufacturers, it is felt that the development costs quoted are unrealistically low.

2.1.2 Magnetically focused klystron. - Only one magnetically focused cw klystron (the Varian 4K3SL),with a power output greater than 100 watts and with a reasonable chance of covering 1650 MHz, was found during the survey. This tube was not designed for airborne use and is quite large and heavy. The pertinent electrical and physical characteristics of the Varian 4K3SL appear below:

Power output	1 kW
Efficiency	33%
Gain	>30 dB
Bandwidth	9 MHz
Weight	85 lb with permanent magnet
Length	18 in.
Diameter	14 in. with permanent magnet

TABLE 1.–CHARACTERISTICS OF AVAILABLE TRAVELING-WAVE-TUBE POWER AMPLIFIERS

Type	Maximum power output, W	Beam efficiency, %	Gain, dB	Instantaneous bandwidth, GHz	Weight, lb	Size, in.	Remarks
Hughes 551H	1000	14 to 16	≥30	2 to 4	20	20 x 3 dia	Solenoid-focused tube, Hughes feels it may work down to 1.65 GHz
Microwave Associates MA 2032	800	~14	25	1.6 to 2.5	21	18 x 4 dia	Solenoid focused
MEC M5477	160 (100 typ)	14	≥30	1 to 2	8	21 x 3 dia	PPM focused
MEC M5477 (Modified)	300 (200 typ)	14	≥30	1 to 2	8	21 x 3 dia	PPM focused
Varian VA-624C	160 (100 typ)	10 to 15	≥30	1 to 2	9.5	24 x 2-1/2 dia	PPM focused

The low-frequency design limit for this tube is 1700 MHz, but Varian engineers are confident that this tube type will satisfactorily tune to 1650 MHz. The price of a single tube would be between $5000 and $10 000. In large production quantities the price of a single-frequency version of this tube, tuned to 1650 MHz, would drop to the neighborhood of $3500.

2.1.3 Electrostatically focused klystrons (ESFK's). - At present there are no ESFK's available that will operate in the 1640- to 1660-MHz band. There is now question, however, that the technology is available to develop such tubes. Characteristics of representative tubes operating at other frequencies are in table 2.

Manufacturers of ESFK's developed the physical and electrical characteristics shown in table 3 for tunable ESFK's over the 1640- to 1660-MHz band.

Based upon the performance of 100-watt ESFK tubes being built for NASA/JPL by EIMAC under JPL contract 951105, it is felt the state of the art in ESFK technology will support a higher efficiency than the 31% to 36% quoted by the manufacturers – perhaps near 45%. However, a higher development cost would be incurred.

TABLE 2.–OPERATIONAL CHARACTERISTICS OF AVAILABLE ESFK'S

Tube type	Frequency, MHz	Power, W
Litton L-5109	2680	250
Litton L-5101	2300	1000
Litton L-5182	4400 to 5000	1000
Litton L-5044	2295	100
EIMAC X3065	2100	200
EIMAC X3065A	2100	500
EIMAC X3064	2300	100

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TABLE 3.—ESTIMATED PHYSICAL AND ELECTRICAL PARAMETERS FOR TUNABLE ESFK'S OVER THE 1640-TO-1660 MHz BAND

Power output	1000 watts	100 to 200 watts	500 watts
3-dB bandwidth	5 to 10 MHz	5 to 10 MHz	
Gain	30 dB	30 dB	
Efficiency	36%	31%	
Maximum diameter	7 in.	6-1/4 in.	
Length	11 in.	9 in.	
Weight, liquid cooled	15 lb		
Weight, air cooled	18 lb		
Cooling (H_2O)	2.0 gpm	0.5 gpm[a]	
Development cost	$60 000	$30 000	$80 000
Second tube	$18 000	$15 000	$10 000
Large quantities (hundreds)	$3000	$2700	$ 5 000

[a]A version using forced air cooling could also be built.

2.1.4 Crossed-field devices. - Although three leading manufacturers of crossed-field devices were contacted, no devices suitable for the L-band terminal were found. Most development of crossed-field devices within the United States has been with an eye toward high-power pulse-radar usage. While cw crossed-field amplifier technology is capable of meeting reasonable power-output, bandwidth, efficiency, weight, and size requirements, the gain performance of crossed-field amplifiers is much poorer than the TWT or klystron amplifiers. In addition, a circulator or isolator is required between the driver and the power amplifier to aid system stability and to provide driver protection.

The amplitron, a power amplifier being developed by Raytheon, is one type of practical crossed-field device for cw communications use. In the amplitron, the electrons emitted by the cathode are given a rotational velocity about the cathode by the action of a normal magnetic field and a radial electric field. The rf input signal travels around the anode structure placed concentrically about the cathode. The electrons traveling in the space between the cathode and anode interact with the rf signal. The energy conversion of this interaction provides amplification to the rf signal which exits after slightly less than one rotation about the cathode.

A device of this type exhibits good efficiency (50% exclusive of power supply and input/output isolators), but it has three inherent drawbacks for L-band terminal applications. First, the presence of an effectively continuous cathode in the interaction region is detrimental. During the energy exchange between the space-charge electrons and the rf signal traveling in the anode structure, some electrons are driven back to impact the cathode. The impact and resultant secondary emission reduces the effective cathode life. Raytheon indicated they could reliably predict tube failure to occur between 2500 hours and 3000 hours.

A second drawback to the amplitron is the inherently low internal isolation between output and input ports, so that if high-stage gain is employed oscillation will occur. To avoid self-oscillation, the tube gain is limited to between 10 dB and 17 dB and isolators are used at the input and output ports to minimize reflections. Raytheon achieves somewhat higher gains by cascading two tubes. Levels of gain above 17 dB are usually realized at the expense of either efficiency or bandwidth and often result in increased noise and spurious signal generation. The alternate is therefore to use several devices in cascade to achieve the overall required gain and power output.

The third problem encountered in using the amplitron lies with the locked operation of the device, which requires recycling of tube voltages if drive is removed. Under certain conditions, the amplitron type of crossed-field amplifier acts as a broadband noise generator in the absence of an input signal. Some other types of crossed-field devices do not have this drawback.

A current application of this device is the two-stage 20-watt amplitron currently being developed by Raytheon for the Apollo LM. Figure 1 is a sketch of the implementation.

Each stage uses a QKS-1300 amplitron with a 25-watt power output. The design is a series standby redundant configuration. One or the other stage is actively used, with the other merely a passive low-loss feedthrough device. The isolators are necessary to prevent regenerative feedback. A 720-mW drive signal will provide 25 watts out of the prime amplitron; considering rf circuit losses, an overall device gain of about 14 dB is realized.

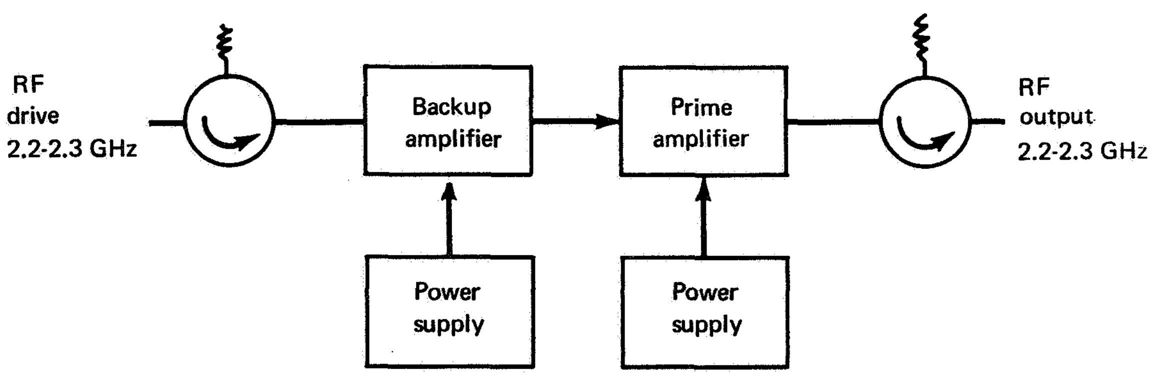

FIGURE 1.– APOLLO LM AMPLITRON AMPLIFIER

2.1.5 Negative-grid devices. - Triode and tetrode tubes can provide up to 100 watts cw at 1650 MHz. However, the gain of these devices is quite low. EIMAC has produced 100-watt triode telemetry amplifiers for the 1435-MHz and 2200-MHz bands. The gain of these amplifiers is on the order of 10 dB for a 7-MHz instantaneous bandwidth. These amplifier packages exhibit 30% to 35% efficiency.

RCA has developed a tetrode, the A2750, which they believe can provide from 100 watts to 150 watts at 1650 MHz with 10% to 15% efficiency and a gain of 3 dB to 5 dB. This information is based on data collected on an A2750 operating at 1800 MHz. The A2750 is an air-cooled tube.

General Electric has developed an experimental water-cooled triode, the L-65/Y1430 (ref. 4). This tube provides 1-kW cw output at 1300 MHz with a gain of 13 dB and 500 watts cw output with a gain of 20 dB. Bandwidth of the amplifier is 15 MHz. However, due to transit-time losses, General Electric predicts the Y1430 would provide less than 100 watts output at 1650 MHz. No lifetime data is available for this tube and not enough application has been found to warrant production of the Y1430. Another General Electric tube (the ZP1043), a triode designed for pulse service, might produce as much as 150 watts cw with a redesigned anode heat sink, but gain would be less than 10 dB.

2.1.6 Solid-state rf power devices. - A survey of solid-state devices applicable to the transmitter portion of the L-band terminal was undertaken primarily to support a possible phased-array antenna design. This survey also proved helpful in the transmitter-driver area. The present state of the art in solid-state power generation at 1650 MHz lies somewhere between 50 watts and 100 watts. Using an experimental multichip traveling-wave varactor doubler, MIT-Lincoln Laboratory has produced 50 watts at 1800 MHz. Typical devices that are commercially available, such as the Bomac VAB-811A, exhibit more than 50% efficiency as triplers to 1650 MHz at power levels around 20 watts. Single-unit cost for the VAB-811A is $65.

The 1968-1969 state-of-the-art power output for single transistors is in the neighborhood of 10 watts to 20 watts at 1650 MHz. Transistors with 10 watts output at 1 GHz and 5 watts at 2 GHz are presently available off the shelf. The TRW 2N5483, for example, provides 5 watts at 2 GHz with a gain of 4 dB at an efficiency of 33%.

It is anticipated that the solid-state technology discussed above will be utilized extensively in the exciter section of the transmitter. Solid-state devices offer substantial volume and weight saving in the terminal hardware; however, temperature compensation is generally required if a wide temperature range must be accommodated. In addition, extensive filtering is often required at the output of solid-state frequency multipliers to meet spurious- and harmonic-output suppression criteria.

A number of potential vendors were asked to describe existing off-the-shelf capability in small crystal-controlled microwave sources. Table 4 lists typical devices presently available and devices proposed by the vendors for the L-band terminal. The Applied Technology LO-100 (item 2 in table 4) is being manufactured on a medium-scale production basis. The cost of this device reflects the large-quantity cost of a 1-watt driver meeting very severe environmental specifications. As expected, the cost of the other devices listed is a strong function of environmental specifications, which reflect the high cost of proper environmental design and testing.

TABLE 4.–SOLID-STATE L-BAND SOURCES

Model	Frequency GHz	Power output, W	Weight, oz	Power, W	Size, in^3	Prototype cost, $	Long-term frequency stability	Remarks
Fairchild MO(L)-110XC	1.65	0.15	15	10	27	525	5×10^{-6} (with oven)[a]	-30 to +60°C external oscillator and modulation option available
Applied Technology LO-100 (modified)	1.00	1.0	24	15	25	2750	2×10^{-6} (with oven)	-54 to +95°C Designed for X-band output Final multiplier removed for L–band service
Bomac proposed unit	1.65	5.0	32	50	40	6500	External osc 100 MHz at 10 mW required	-30 to +60°C Large-quantity price: $1000 each
Bomac proposed unit	1.65	1.0	22	20	28	5700	External osc 100 MHz at 10 mW required	-54 to +71°C Large-quantity price: $500–$800 each
Micromega proposed unit	1.65	5-10		70	45	1500	10^{-6} (with oven)[a]	+5 to +35°C Large-quantity price: $500-$700 each
Microwave Associates proposed unit	1.65	5.0				7500	10^{-7}	Large-quantity price: $800

[a] Phase-locked type

2.2 Low-Noise Receiver Front-Ends

The survey of receiver front-end devices included the 1968 state of the art in tunnel-diode and transistor amplifiers, parametric amplifiers (both cooled and uncooled), crystal mixers, and traveling-wave tubes. Although none of the devices presently available were developed specifically for the 1540- to 1560-MHz frequency assignment, many receiver front-ends have been built which operate in nearby telemetry bands. In particular, equipment built for the 1435- to 1540-MHz band can be easily modified to provide the mixer, first local oscillator, and i.f. amplifier of the L-band terminal receiver. In addition, broadband low-noise amplifiers, operating over the 1- to 2-GHz range, are presently available. Typical examples are the TWT and transistor amplifiers discussed below.

All devices considered offer potential noise figures below 6 dB. All noise figures given are single-sideband (SSB) noise figures; that is, the noise figure was either measured with image suppression or corrected for image noise.

In fairness to the vendors who supplied much of the information contained in the following sections dealing with receiver front-end technology, it must be emphasized that most price data included in these sections is purely budgetary. Figure 2 shows the cost of low-noise front-end devices as a function of noise temperature. The costs are based on quantities of one or two for the experimental terminal.

2.2.1 Tunnel diodes. - Very few L-band tunnel-diode amplifier (TDA) models are presently available since in many applications they have been replaced by low-noise transistor amplifiers. At 1540 MHz, tunnel-diode amplifiers can provide 4.0- to 4.5-dB noise figures with gains of 15 dB to 25 dB and 1-dB bandwidths exceeding 20 MHz. TDA's with very uniform response over narrow bandwidths can be easily fabricated. For example, at gain levels near 15 dB it is possible to achieve a 20-MHz bandwidth at the 0.1-dB points with the passband flat within ±0.05 dB.

TDA's can be made quite rugged and insensitive to shock and vibration. TDA's have withstood shocks of (1) 60 g for 7 msec and (2) 250 g for 1 msec; and vibrations of (1) 20 Hz to 2000 Hz at 20 g; and (2) 2-minute acceleration at 60 g. The above performance is far in excess of any required in an airborne environment. Tunnel-diode amplifiers are somewhat temperature sensitive, and some form of temperature compensation or environmental control is required whenever the environment includes temperature variations from below -10°C or -20°C to above 60°C. Compensation can take the form of a temperature-sensitive bias network or a simple oven to provide an alternate environmental control.

Due to the TDA single-port configuration, tunnel-diode amplifiers require a circulator isolating the input and output to provide a low noise figure and high-stability operation. Additional isolation, above that provided by a three- or four-port circulator, is recommended for amplifiers with more than 15 dB of gain. Two typical TDA configurations are shown in fig. 3.

Tunnel diode amplifiers can withstand at least 100 mW of input power without permanent degradation.

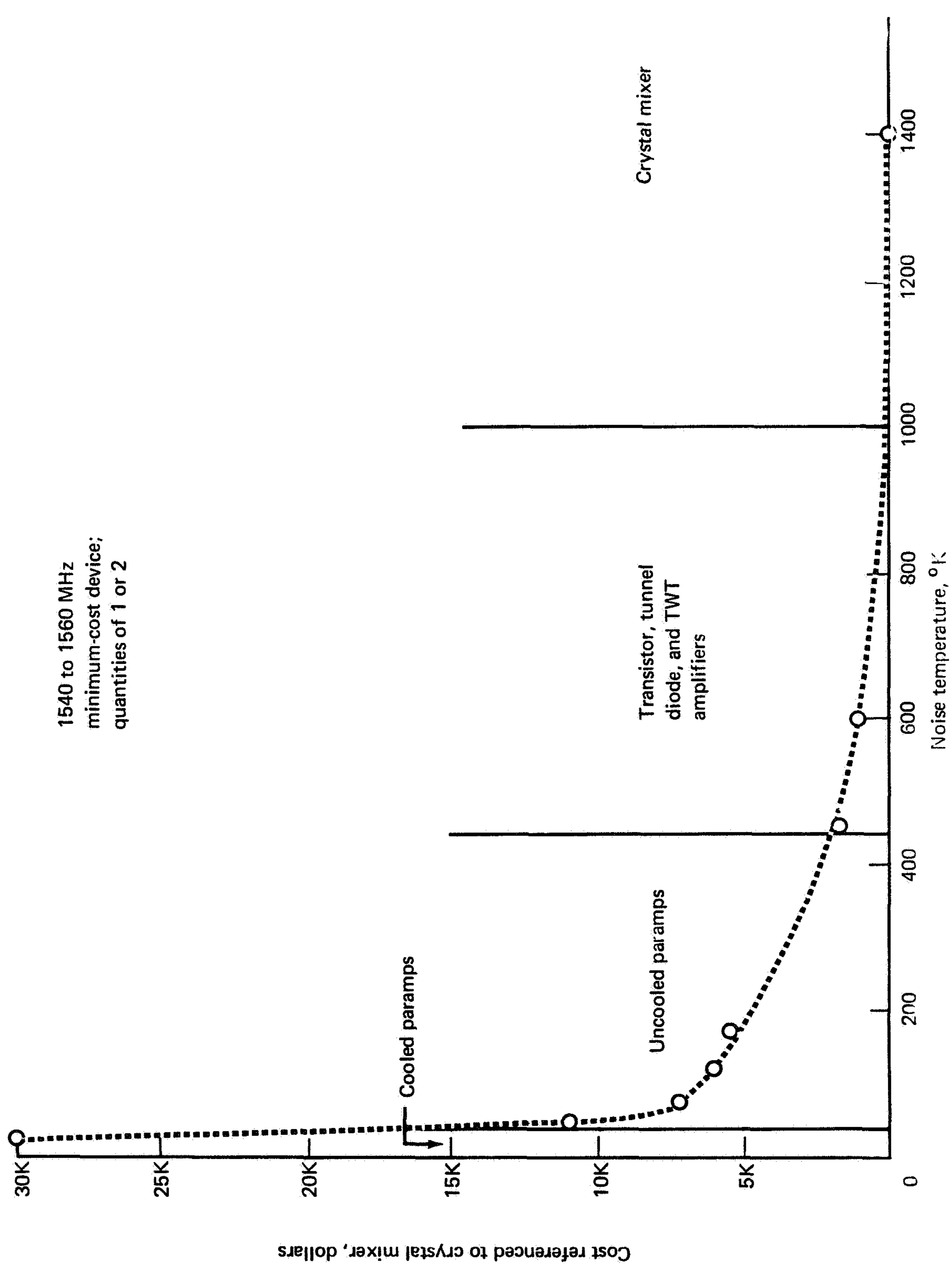

FIGURE 2.– COST OF LOW-NOISE PREAMPLIFIERS

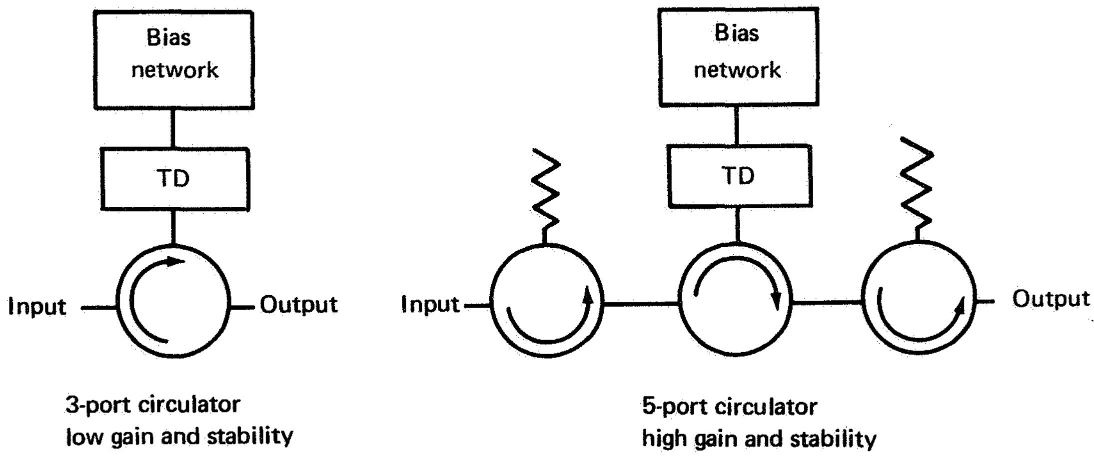

FIGURE 3.– TUNNEL-DIODE AMPLIFIER CONFIGURATIONS

One typical TDA suitable for L-band is the International Microwave Corporation model ACH-1700-20. It provides the following performance:

1-dB bandwidth	1650 to 1750 MHz
Gain	20 dB
Noise figure	4.5 dB maximum
Gain variation.............	±1 dB, -10°C to 55°C
Power required............	< 1 watt
Volume	10 in^3

2.2.2 Transistors. – The present state-of-the-art noise figure for low-noise transistor preamplifier technology is near 4 dB at 1600 MHz. A noise figure of 3.8 dB for a transistor amplifier has been measured at 1700 MHz – 4.0 dB is readily achieved in practice and 4.5 dB is guaranteed by some vendors. Gain per stage of 10 dB is typical and 12 dB per stage is easily obtained for bandwidths of 15% or less. There is surprisingly little variation in performance between transistors manufactured by either domestic or foreign semiconductor companies; therefore, most amplifiers on the market are quite comparable in noise figure and gain-per-stage performance. Performance of off-the-shelf units is typified by the Avantek model AM-1435 and the Applied Technology model SP-1500/1000, compared in table 5.

Another example is the TA series of amplifiers manufactured by International Microwave. At 1540 MHz, units with a 20°C noise figure of 4.0 dB and a gain of 20 dB or more are available. For a 15-dB-gain version, the power requirement is less than 1 watt; each amplifier occupies 9.5 in^3, and each has a ±2 dB gain variation over a temperature range of -55°C to 85°C. The cost in small quantities is $800, but in quantities of 100 or more, the price might drop to $350 to $400.

TABLE 5.– TRANSISTOR FRONT-END PERFORMANCE

Specification	AM-1435	SP-1500/1000
Instantaneous bandwidth	1435 to 1550 MHz	1000 to 2000 MHz
Noise figure		
Guaranteed	5.0 dB	7.0 dB
Typical	4.5 dB	5.0 dB
Gain		
Minimum	25 dB	25 dB
Typical	28 dB	28 dB
Gain flatness	±0.75 dB	±1 dB
Gain variation		±2 dB (-54° C to + 71°C)
Weight	12 oz	4.8 oz
Power required	0.5 W	0.5 W
Volume	11 in ^{3}	4 in ^{3}
Cost (each)	$1500	$1950
Cost (>100, each)	$1000	$1450

2.2.3 Uncooled paramps. – Room-temperature nondegenerate parametric amplifiers (paramps) can provide noise temperatures as low as 50°K at L-band. The noise figure of a parametric amplifier is dependent upon the pump frequency, signal frequency, and the quality of the varactor. For a given signal frequency and varactor, the noise figure of the paramp will improve as the pump frequency is increased. Normally in a very low-noise L-band paramp, the pump frequency is 10 to 15 times the signal frequency (i.e., 20 GHz to 30 GHz). Typical nondegenerate single-stage and double-stage paramp configurations are shown in fig. 4.

In common with other negative-resistance devices, such as the tunnel-diode amplifier, gain stability of paramps is a strong function of gain and environment. The greater the pump power incident upon the varactor in a parametric amplifier, the greater the amount of negative resistance generated, and, therefore, the greater the power gain of the paramp. However, the higher the amplifier gain, the more sensitive it becomes to pump power fluctuations. It is therefore important to avoid operation at too high a gain level because of stability considerations. As a result, the gain of most single-stage paramps is limited to the 15- to 20-dB range with 17 dB to 18 dB being a common compromise.

When gain stability is to be maintained within close tolerances, temperature stabilization is necessary. At the 17- to 18-dB gain level, paramps require environmental control whenever the temperature environment varies more than 15°C from nominal.

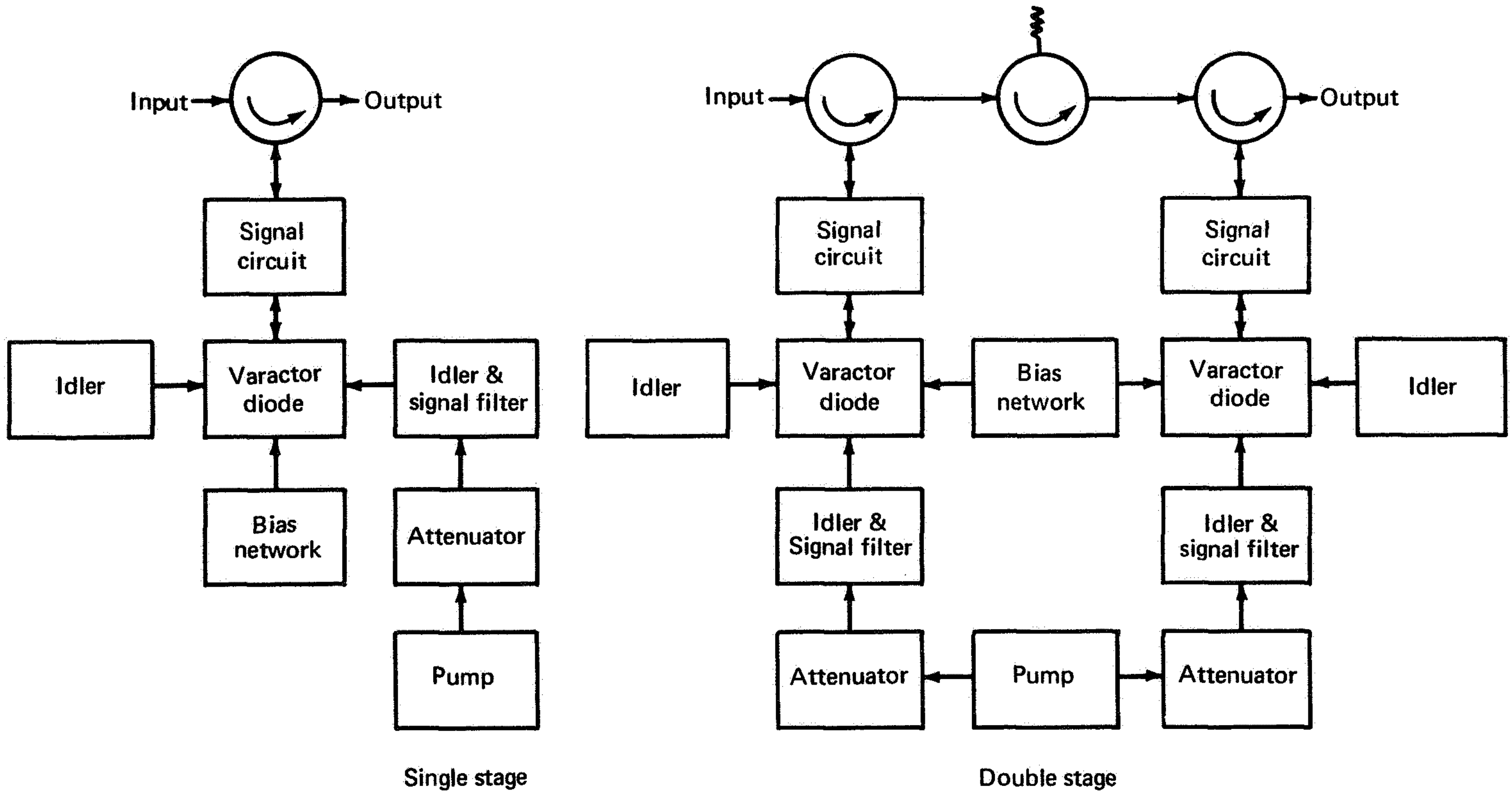

FIGURE 4.– PARAMP CONFIGURATIONS

The gain-bandwidth of single-tuned paramps is substantially constant. As paramp gain is increased, bandwidth is decreased. This effect occurs because the Q of the paramp signal circuit is increased when pump power is increased, and the circuit bandwidth is therefore decreased. There is no problem in achieving 20-MHz bandwidth at 1540 MHz with single-stage gain levels below 20 dB. Very wide bandwidths can be obtained by using a multiple-tuned signal circuit.

Since the nondegenerate paramp is a single-port device, a circulator is required to isolate the input and output. Because of the isolation provided by the circulator (and by any additional input and output isolation), paramp gain can be made unconditionally stable with respect to generator and load impedances.

Parametric amplifiers themselves are solid-state devices (with the possible exception of the pump source, which is usually a klystron). At present, solid-state pump sources, such as avalanche-diode oscillators, are available that can replace the klystron; however, these devices have a higher noise output than the klystron and in extreme cases cause noise-figure degradation in the paramp. In addition, solid-state pump sources have less power and frequency stability with respect to temperature variation than do klystrons.

Development of low-noise solid-state pump sources continues, and improvement in solid-state pumps is expected. By hand-selecting individual K-band Gunn-effect oscillators, one vendor was able to build a completely solid-state 2.2- to 2.3-GHz room-temperature paramp which provided a 77°K noise temperature (compared with 75°K noise temperature when pumped by a klystron). This performance was not repeatable with other Gunn oscillators but it does represent the state of the art in solid-state pumps.

From the standpoint of paramp-varactor protection, transmitter leakage should be held below 100 mW. However, most paramps should be able to handle leakage levels as high as 1 watt without permanent degradation.

The characteristics of several representative room-temperature parametric amplifiers are listed in table 6. Since there has been little or no equipment development or production work in the 1540- to 1560-MHz frequency assignment, the parametric amplifiers listed operate at nearby frequencies. Scaling to within 10% of existing device frequencies should result in essentially no performance degradation, however. A 50° K uncooled paramp device is seen as feasible for aircraft terminal use should such a selection be made.

2.2.4 Cooled paramps. - Providing the antenna temperature is low enough to warrant the additional complexity, a cooled paramp can provide a significant increase in receiver-system performance. Assuming an attainable room-temperature paramp noise temperature of 50° K to 70° K: if the paramp is cooled to a temperature of 77° K (liquid N_2), an amplifier noise temperature of 25° K can be achieved at 1600 MHz; if cooled to 20° C (gaseous helium refrigeration), the noise temperature will drop to around 12° K.

This decrease in system-noise temperature is accompanied by a significant increase in preamplifier cost, complexity, weight, size, power requirements, and maintenance requirements. According to one cooled-paramp vendor, the cost of a cooled paramp with a 12° K amplifier noise temperature would be near $30 000. The unit would require a vacuum chamber surrounding the parametric amplifier, a compressor pump for the helium, and a vacuum pump. The vacuum chamber could be pumped down by ground-support equipment and would not be required as part of each installation.

TABLE 6.—CHARACTERISTICS OF ROOM-TEMPERATURE PARAMETRIC AMPLIFIERS (PARAMPS)

Make & model	Frequency range, MHz (a)	Noise temperature, °K (b)	Gain, dB	Pump frequency, GHz	Pump power, mW	Thermal gain coefficient	Volume, in^3	Weight, lb	Power, W	Remarks
Melabs APS-3E	2200 to 2300	150 typ	22	11	100 max	± 1 dB -54° to +71°C	360	10	200	• Two stage • Includes environmental control • Solid-state pump • Stagger tuned • $5800
Micromega 26339	1350 to 1430	50 typ 70 max	18.5	20.8	50 max	-0.1 dB at 25°C	200	9	40	• Double tuned • Operates in room-temperature environment; environmental control not included • $11 500 • Single stage
Melabs APL-4	1435 to 1540	100 max	22	18	100 max	±1 dB -54°C to +71°C	750	27.5	250	• Two stage • Environmental control • Stagger tuned
Melabs APS-3	2200 to 2300	150 typ	22	11	100 max	±1 dB -54°C to +71°C	750	27.5	250	• Remarks same as for APL-4
AIL 4012	1657 to 1667	70	15 to 20							

[a]Instantaneous bandwidth
[b]Including circulator contribution

For a typical 20°K refrigeration system (exclusive of paramp, vacuum chamber, and vacuum pump), the refrigeration unit and compressor unit together weigh 24.7 pounds, require 595 watts, occupy 500 in^3, and have dimensions which preclude confinement within ARINC-404 packaging constraints.

2.2.5 Crystal mixer, i. f. preamplifier. – L-band coaxial hybrid mixers combined with transistorized i.f. preamplifiers are commercially available and can provide noise figures of 7.5 dB and rf to i.f. gains of more than 20 dB. Experimental mixers, employing Hewlett-Packard hpa-2400 hot-carrier diodes, have exhibited noise figures of less than 6 dB at 2 GHz. Watkins-Johnson has built an integrated-circuit front-end that yields a noise figure of 6.2 dB to 6.5 dB from 2.1 GHz to 2.4 GHz with an rf-to-i.f. gain of 12 dB. The Watkins-Johnson mixer and two-stage i.f. preamplifier occupies 2 in^3. The characteristics of two off-the-shelf units are given in table 7.

2.2.6 Traveling-wave tube (TWT). – Low-noise traveling-wave-tube amplifiers, providing 4 dB noise figure and 20 dB gain, are currently available. In general, their power requirements, cost, size, and weight are much higher than those of a transistorized amplifier with equivalent electrical characteristics. The pertinent characteristics of two low-noise TWT's, indicating the present capabilities of TWT's, are listed in table 8. The cost reflects the inclusion of an integral power supply for operation from 115 volts ac, 50- to 400-Hz primary power.

2.3 Transmission Lines

One of the most important areas of the terminal design, carrying perhaps the greatest system-weight penalty and affecting both receiver and transmitter requirements, is the transmission line between the antenna and other system components. If a relatively low-loss transmission line together with a relatively short line length is considered, it will be possible to place the transmitter and receiver together in the avionics rack area of the aircraft. If there is a firm weight constraint coupled with a requirement for a long transmission line, due to relative placement of the transmitter and antenna, a small light transmission line may be required. As a result, the line may be rather lossy, and thus may require that the receiver front-end be located with the antenna.

The characteristics of representative waveguide and coaxial transmission lines for the 1540- to 1660-MHz band are discussed below. Power handling capability of a transmission line is limited by either dielectric breakdown or temperature rise: in waveguide, the power is primarily limited by breakdown; and thermal effects generally limit the power handling capability of coaxial transmission lines at L-band. It is assumed that air-filled transmission lines will be pressurized to cabin pressure to avoid breakdown. If portions of the transmission line are unpressurized, consideration must be given to the effect of voltage breakdown as a limitation upon power-handling capability. In the case of coaxial transmission lines, this unpressurized condition is further complicated by the lack of suitable heat conduction away from the center conductor to the shield. This effect lowers the thermal power-handling limit of the unpressurized transmission line at higher altitudes. As an example, fig. 5 shows power-handling capability based upon voltage breakdown as a function of altitude for 7/8-inch 50-ohm coax. Obviously, if the transmission line remains pressurized to the 10 000-foot maximum cabin altitude, voltage breakdown effects may be neglected.

TABLE 7.– CHARACTERISTICS OF CRYSTAL MIXER IF PREAMPLIFIERS

Specification	International Microwave Model MPC 30	LEL Model LAK-7-60
Frequency range	1-2 GHz	0.9 to 1.8 GHz
Noise figure	7.5 dB	8.0 to 9.0 dB
RF-to-IF gain	30 dB	24 dB
Volume	12 in^3	
Gain variation -55°C to +71°C	± 1.5 dB	
Local oscillator power	~ 2 mW	1-4 mW

TABLE 8.—CHARACTERISTICS OF TWO CURRENTLY AVAILABLE TRAVELING-WAVE-TUBE AMPLIFIERS

Specification	Varian VAS-413P2	Watkins-Johnson WJ-370-1
Frequency range	2700 to 3100 MHz	1435 to 2300 MHz
Maximum noise figure	5.0 dB	4.5 dB
Minimum saturated gain	25 dB	20 dB
Weight	<7 lb	17 lb
Power	7.5 W	15 W
Volume	108 in^3	180 in^3
Cost (each)	$3500	$3500[a]
Cost (>100, each)	$1800	

[a]A selected Watkins-Johnson model WJ-268 will provide a 4-dB noise figure at 1540 MHz at a cost of $4000 each.

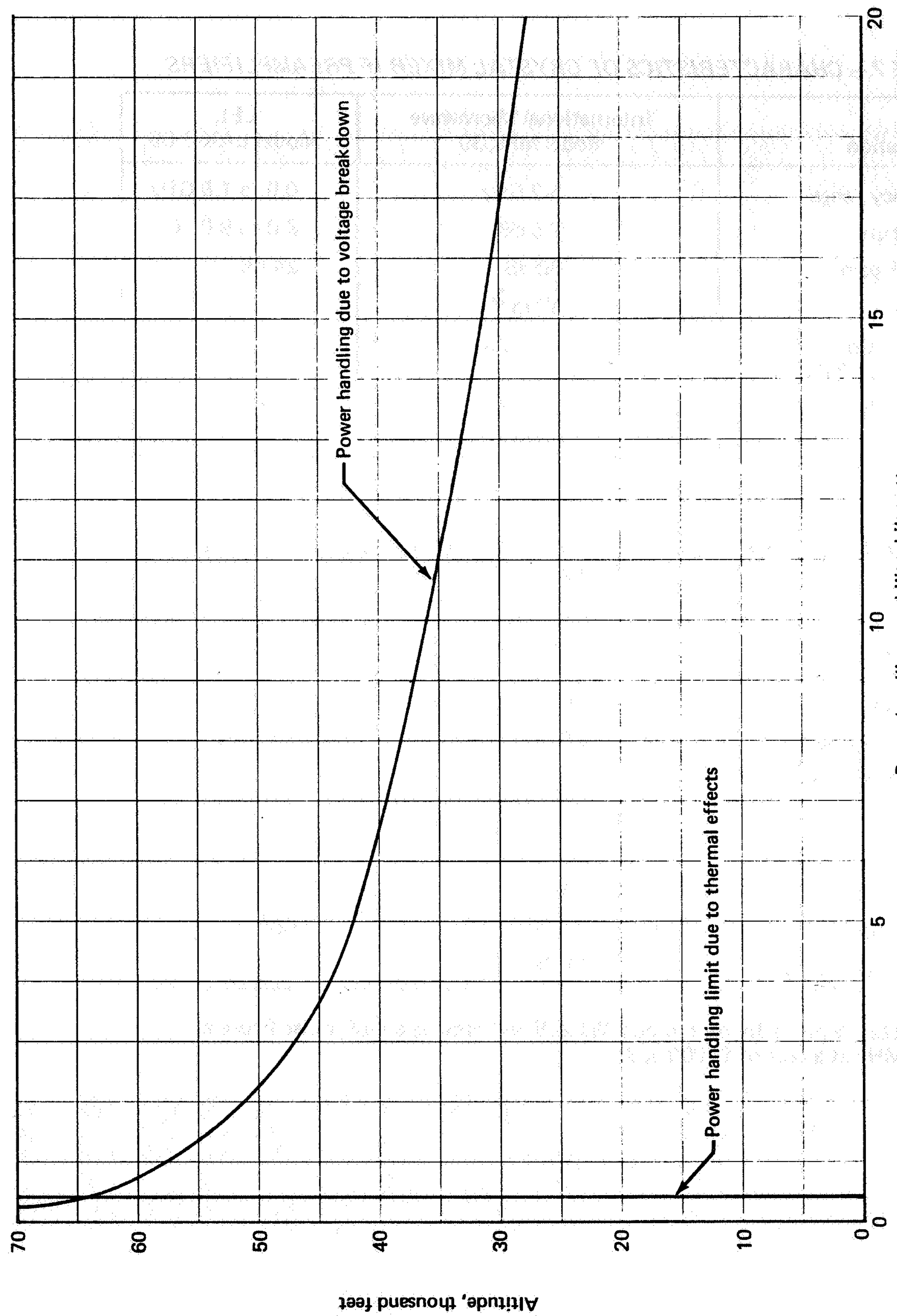

FIGURE 5.– POWER HANDLING CAPABILITY OF 7/8-INCH 50-OHM COAX

Note also that the 82°C temperature environment in some cable-run areas on the SST aircraft precludes the use of a low-temperature dielectric (such as polyethylene) in coaxial systems. However, when the antenna location is fixed and the cable-run environment becomes more precisely defined, it is recommended that an evaluation of a mix of polyethylene and high-temperature cables be made. The use of polyethylene dielectric cables in subsonic aircraft should present no problems if suitably derated for environment and if consideration is given to the high attenuation.

2.3.1 Waveguides. - Available waveguide for this band can be subdivided into three classes: rectangular, elliptical, and circular. Standard lightweight-aluminum waveguide for this frequency range is WR-430 (RG-105/U). It weighs 1.26 pounds per foot, has a theoretical attenuation of 0.77 dB per 100 feet at 1540 MHz and 82°C, and can handle over 20-kW cw power at sea level for a temperature rise of 25°C above 55°C ambient with 1:1 VSWR, and has outside dimensions of 4.46 inches by 2.31 inches.

Andrews Corporation manufactures a flexible waveguide of elliptical cross section for the 1700- to 2400-MHz frequency range. This elliptical waveguide carries the designation EW-17. The calculated attenuation constant of copper EW-17 at 82°C with a VSWR of 1.5:1, at 1540 MHz, is 0.67 dB per 100 feet, and it can handle over 20-kW cw power. Copper EW-17 weighs 2.73 pounds per foot and its widest outside dimension is 5.68 inches. It is not known if an aluminum or other lightweight version of EW-17 is available. The greatest advantage of the flexible EW-17 is that it is currently available in continuous lengths of greater than 200 feet, thereby simplifying installation.

Standard circular waveguide for the 1540- to 1660-MHz band is WC-528. It has an outside diameter of 5.44 inches, weighs 1.84 pounds per foot for aluminum WC-528, and has an attenuation constant of 0.34 dB per 100 feet at 1540 MHz and 82°C. As with the rectangular and elliptical waveguide, the power handling capability is more than adequate.

With circular waveguide, attention must be paid both to keeping the E vector within the waveguide properly oriented at waveguide-to-coaxial transitions and the prevention of coupling to higher-order modes. The latter problem can be solved by choosing the waveguide size such that the TE_{11} mode will propagate, but with the line still below cutoff for the next highest modes (TM_{01} and TE_{01}). This criterion will be satisfied with WC-528 waveguide operating between 1540 MHz and 1660 MHz.

One promising approach for weight reduction of waveguide transmission lines is the use of fibreglass waveguide. Microwave Components and Systems, Inc. has conducted experimental studies at X-band with waveguide consisting of a thin metallic sheet inner surface covered by a fibreglass outer surface for mechanical strength. One advantage of this type of construction is the ability to form unusual shapes and bends in the waveguide during manufacture. According to the manufacturer, the electrical characteristics would be very similar to conventional WR-430; but, with development, a density of only 0.7 pound per foot may be realized.

2.3.2 Coaxial. - The scope of a survey of coaxial transmission lines is restricted by both operational and environmental constraints. The operational constraints include frequency, power level, and VSWR at the load. Input power levels of 100 watts to 1000 watts have been considered. A frequency of 1540 MHz to 1660 MHz and a VSWR of 1.5:1 have been assumed. The most significant environmental constraint is temperature. Within the SST airframe, cable-run area temperatures as high as 180°F (82°C) will be encountered. In the wings and near the skin, the temperature will approach 500°F (260°C).

The temperature environment rules out the use of polyethylene dielectric in the coax due to the thermal instability of polyethylene above 80°C (RETMA Standard TR-143). Teflon-dielectric cables have satisfactorily passed electrical and mechanical tests relating to the SST program at temperatures as high as 260°C (ref. 5). Although cables using teflon dielectric may be used at much higher temperatures, solid-dielectric cables exhibit high attenuation at L-band and are considerably heavier than air-dielectric coax of equivalent loss. Teflon-dielectric cable does have slightly improved power handling performance as compared with air-dielectric cable due to the improved heat transfer from the center conductor to the shield.

Coaxial transmission lines meeting the above constraints are listed in table 9. As most power-handling data are given for 1:1 VSWR and a 40°C ambient temperature environment, manufacturers' data have been derated by a factor of three to compensate for the 82°C ambient temperature and the antenna system VSWR at the transmit and receive frequencies (which is assumed to be below 1.5:1).

2.4 Conclusions and Recommendations

The goals of the experimental system cannot be expected to support the excessive costs of individual component design efforts except in an area where no device exists that will provide the performance required for the terminal. The following recommendations are based on this reasoning. No state-of-the-art advances are required in any areas of the rf subsystem. Devices exist, albeit nonoptimum, which enable the power amplifier to provide up to 1000 watts output. Receiver noise temperatures as low as 50°K are realizable without resorting to preamplifier cooling systems. Transmission line losses may be reduced to extremely low values; however, this is at the expense of system weight and size.

Different ground rules exist for the operational and experimental terminals, and recommendations for each are discussed in the following paragraphs. The operational system must certainly conform to aircraft-electronics packaging and maintenance constraints. These constraints can be eased if they are found to be too costly or unreasonable in the experimental terminal; however, to ensure a meaningful system evaluation the experimental terminal should conform as much as possible to the constraints which will be imposed upon the operational system.

<u>2.4.1 Transmitter.</u> – If the experimental terminal transmitter power-output requirement is in the 100- to 300-watt range, a TWT is recommended. Typical TWT's, suitable for this application, are the Varian VA-624C and the Microwave Electronics Corporation M5477. Of these two tubes, the M5477 has the best form factor for airborne packaging.

If the power required for the experimental terminal is between 300 watts and 1000 watts, either a TWT or magnetically focused klystron is recommended. Since efficiency becomes important from the standpoint of primary power and cooling (if output power levels approaching 1 kW are considered), the higher efficiency klystron may prove more desirable than the smaller and lighter TWT. At a 1-kW power output level, and assuming 85% beam-power-supply efficiency, the Hughes 551H TWT requires 8620 watts of primary power while the Varian 4K3SL klystron requires 3610 watts. Not only is prime power a problem with available broadband TWT's, but the methods of heat removal for each type of device must be considered. The 551H TWT must dissipate approximately three times the heat dissipated by the 4K3SL klystron.

TABLE 9.—COAXIAL-CABLE CHARACTERISTICS

Type	Dielectric (a)	Attenuation, dB/100 ft (b)	Power, W (c)	Weight, lb/100 ft	Outside diameter, in.
Amphenol 421-121	Teflon	7.1	670	50.3	0.770
7/8-in. rigid copper	Air	2.1	330	65.0	0.875
1-5/8-in. rigid copper	Air	1.1	1030	125.0	1.625
1-5/8-in. aluminum heliax	Air	1.2	1000	73.0[d]	2.000
7/8-in. aluminum heliax	Air	2.1	430	38.0[d]	1.115
1-5/8-in. copper heliax	Air	1.1	1015	72.0	2.000
7/8-in. copper heliax	Air	1.9	470	43.0	1.005
1/2-in. copper heliax	Air	4.1	170	21.0	0.500
3/8-in copper heliax	Air	5.3	100	12.0	0.375

[a]Air cables have teflon spacers
[b]1600 MHz, 82°C, 1.5: 1 VSWR
[c]1650 MHz, 82°C, 1.5:1 VSWR
[d]With protective jacket

For the 100- to 1000-watt operational terminal (which must adhere to more rigid packaging constraints than the experimental package), a narrowband high-efficiency TWT or an ESFK is recommended. In either case, development of a special tube for the 1640- to 1660-MHz range will be required. However, the potential market of an operational system should be sufficient to encourage several power-tube manufacturers to develop the necessary devices.

Crossed-field devices should be given further consideration for use in the operational system, especially if future developments promise satisfactory gain and lifetime improvement. Due to the present limitation in power output available from solid-state devices, they are recommended for power levels of 100 watts and less for the operational time period.

2.4.2 Receiver.– An uncooled parametric amplifier (paramp) preceding a low-noise transistor amplifier is recommended for the experimental terminal. Since the experimental terminal may be required to operate with a lower-EIRP satellite than will the operational terminal, the experimental airborne terminal must be designed to provide the additional system margin required. Thus a lower-noise-figure receiving system is recommended for the experimental terminal than that desirable from an economic and maintenance standpoint in an operational system. In addition, the use of a low-noise parametric amplifier will permit more valid measurement of the L-band aircraft-noise environment.

The transistor amplifier following the paramp will provide additional rf gain and will contribute far lower second-stage noise to the overall system-noise temperature than will a mixer alone. In addition, it is desirable to compare terminal operation with and without the paramp so that a separate transistor preamp or a method of bypassing the paramp to connect the diplexer directly to the transistor amplifier is recommended.

A suitable nondegenerate parametric amplifier, providing a noise temperature of 50°K, would have a low-forward-loss (0.2 dB) four-port circulator and would utilize a pump frequency near 25 GHz. In the experimental system, there is no advantage in recommending a solid-state pump other than for the slight weight and size reduction. The transistor amplifier following the paramp should provide 20- to 25-dB gain and a noise figure of 4.0 dB to 4.5 dB. Both the paramp and the transistor amplifier should exhibit sufficient gain stability with changes in environment to allow long calibration-free measurement periods on the aircraft. There are a number of competent manufacturers who can supply these units.

The satellites for the operational system should be configured so that a transistor or tunnel-diode preamplifier, providing a preamplifier noise figure near 4.0 dB to 4.5 dB, will provide reliable system operation for the airborne terminal. It is recommended that serious consideration be given during operational-terminal design to the microwave integrated-circuit techniques presently being developed by a number of rf-system manufacturers. Using these techniques, a complete receiver front-end—containing a multistage low-noise transistor amplifier, mixer, first local oscillator, and a multistage first i.f. amplifier—could be integrated into one assembly. In large production quantities, unit costs would potentially be far lower than front-end designs with individually wired components. For replacement purposes, uniformity is thus ensured. There are a number of companies active in the microwave integrated-circuit field, including: Microwave Associates; Applied Technology Division of Itek; Avantek; Watkins-Johnson; Sanders Associates; and Airborne Instruments Laboratory.

2.4.3 Transmission line. – Full advantage can be taken of low antenna noise temperatures and low-noise receiver preamplifiers only when low-loss transmission line is used between them. If the area of the aircraft immediately behind the antenna is readily accessible and of sufficient volume, it may be possible to mount the diplexers and preamplifier adjacent to the antenna; otherwise, a length of feedline is required between the preamplifiers and the antenna. Any line loss between the transmitter and antenna will of course require additional power output from the transmitter to meet aircraft EIRP requirements.

Figure 6 depicts the receiver-performance penalties associated with different transmission-line arrangements. Antenna temperatures T_a shown represent three possible experimental-terminal antennas: a top-centerline low-gain antenna (T_a = 133° K); the same antenna moved 30° to 40° off the centerline (T_a = 190°K); and a 10-dB-gain beam antenna (T_a = 30°K).

As an example, consider an uncooled-paramp preamplifier (50° K) used on a terminal with an antenna temperature of 30° K. The overall system noise temperature is 250° K when a long run of coax is necessary between the antenna and preamplifier, as compared to a system temperature of 150° K when the preamplifier is located with the antenna. The resulting penalty in receiver threshold is 2.2 dB if the long transmission line is used. The effect of line loss on system temperature becomes less significant as the input antenna temperature rises. For the same paramp and the 190° K antenna temperature, the variation in line loss results in a system temperature range of 280° K to 330° K (0.7 dB).

Depending on the type and location of the antenna selected and assuming that weight and size constraints do not preclude its use, circular waveguide is recommended for transmission-line requirements longer than 20 feet to 30 feet. Otherwise, 7/8-inch air-dielectric coaxial line is recommended for power levels up to 450 watts and 1-5/8 inch air-dielectric coaxial-line for power levels up to 1000 watts.

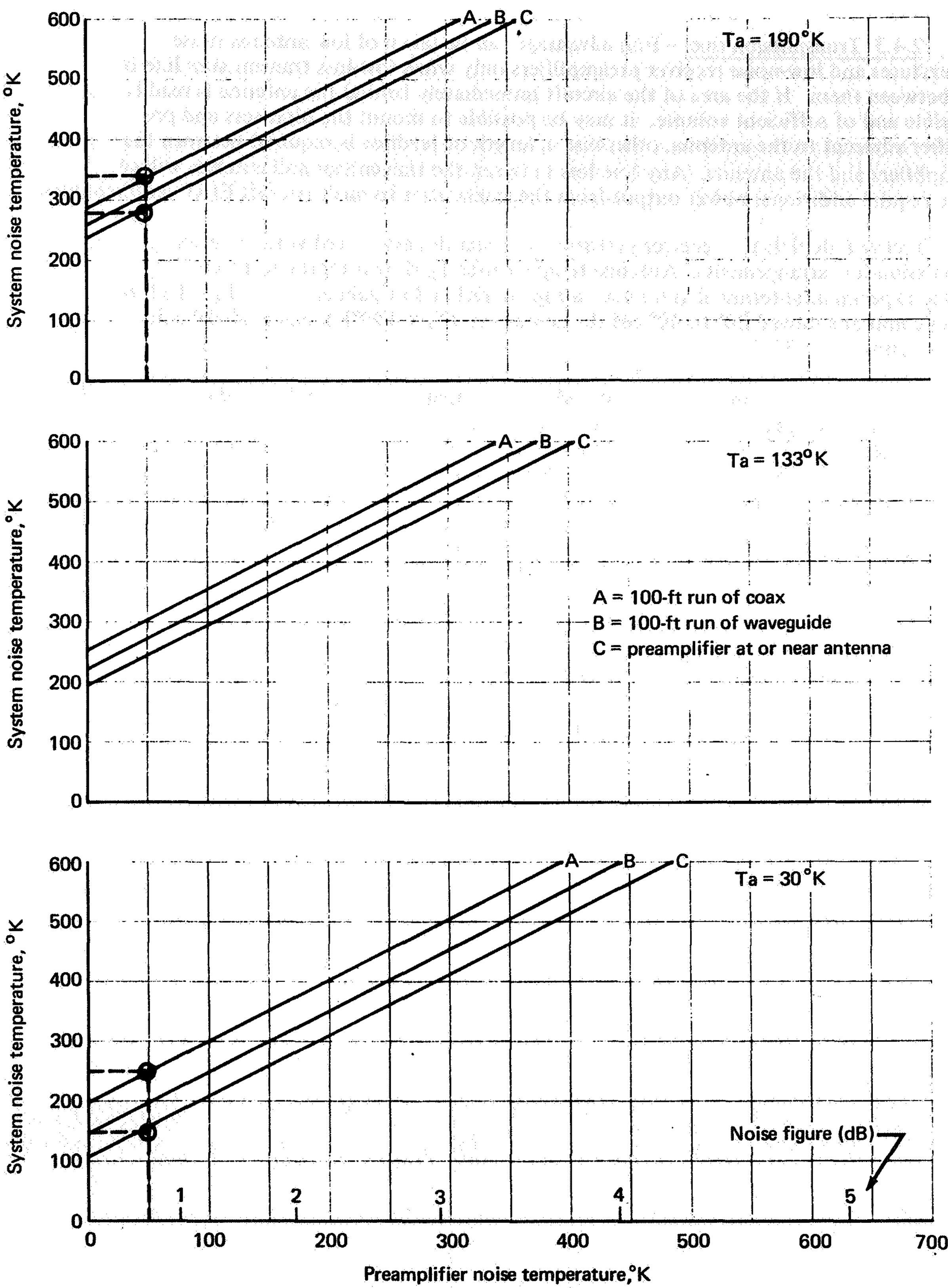

FIGURE 6.– PREAMPLIFIER, ANTENNA, AND SYSTEM-TEMPERATURE TRADEOFFS

3.0 EXPERIMENTAL-TERMINAL FUNCTIONAL DESCRIPTION

A detailed description of the proposed SST aircraft terminal for the experimental phase of the L-band satellite/SST communications/surveillance program is presented in this section. The recommended terminal, along with alternate features as applicable, evolves from the preceding analysis and survey tasks from which the functional and performance requirements of the terminal are determined. Where trade areas still exist, such as the option among several possible antenna configurations and the choice between tone and BINOR surveillance schemes, design features are described for each alternate. Furthermore, since it is possible that both surveillance techniques might be evaluated during the experimental program, the experimental terminal is configured to be capable of evaluating both schemes.

The initial hardware phase of the program will be directed at the development, testing, and demonstration of an experimental version of the system to prove concept feasibility and provide data on system performance. The experimental terminal might therefore incorporate only certain functions of the actual operational system. For example, it is likely that only one satellite will be available for the experimental system, so that the complete surveillance system, which requires several satellites, would not be demonstrable unless the additional satellites were simulated at ground locations as described in Sec. 4.0. Similarly, only one voice channel might be demonstrated, even though the operational system would incorporate multiple channels. The experimental terminal design, however, is chosen to be as nearly identical as possible with the proposed operational system so that the operations, requirements, and performance of the operational terminal can be determined accurately from the experimental phase of the program.

A functional diagram is shown in fig. 7 for the four subsystems that comprise the experimental terminal: the rf subsystem, the surveillance and data subsystem, the voice subsystem, and the BINOR subsystem. The following sections discuss performance requirements and constraints of the experimental terminal; provide functional descriptions of the rf, surveillance and data, and voice subsystems; and summarize the terminal physical characteristics and interfaces. The characteristics of the BINOR subsystem are as developed previously by the system contractor TRW in the NAVSTAR study (ref.6).

3.1 Performance Requirements and Constraints

The experimental terminal aboard the SST must operate under the following requirements and constraints.

3.1.1 Rf subsystem. - The rf subsystem is required to:

(1) Provide one or more antennas of sufficient gain and coverage for reception of the forward voice and surveillance signals at specified frequencies within the 1540- to 1560-MHz band

(2) Use the same antennas for transmission of the return voice and surveillance signals at specified frequencies within the 1640- to 1660-MHz band

(3) Provide sufficient isolation of the received and transmitted signals

(4) Amplify the incoming forward signals with one or more low-noise preamplifiers

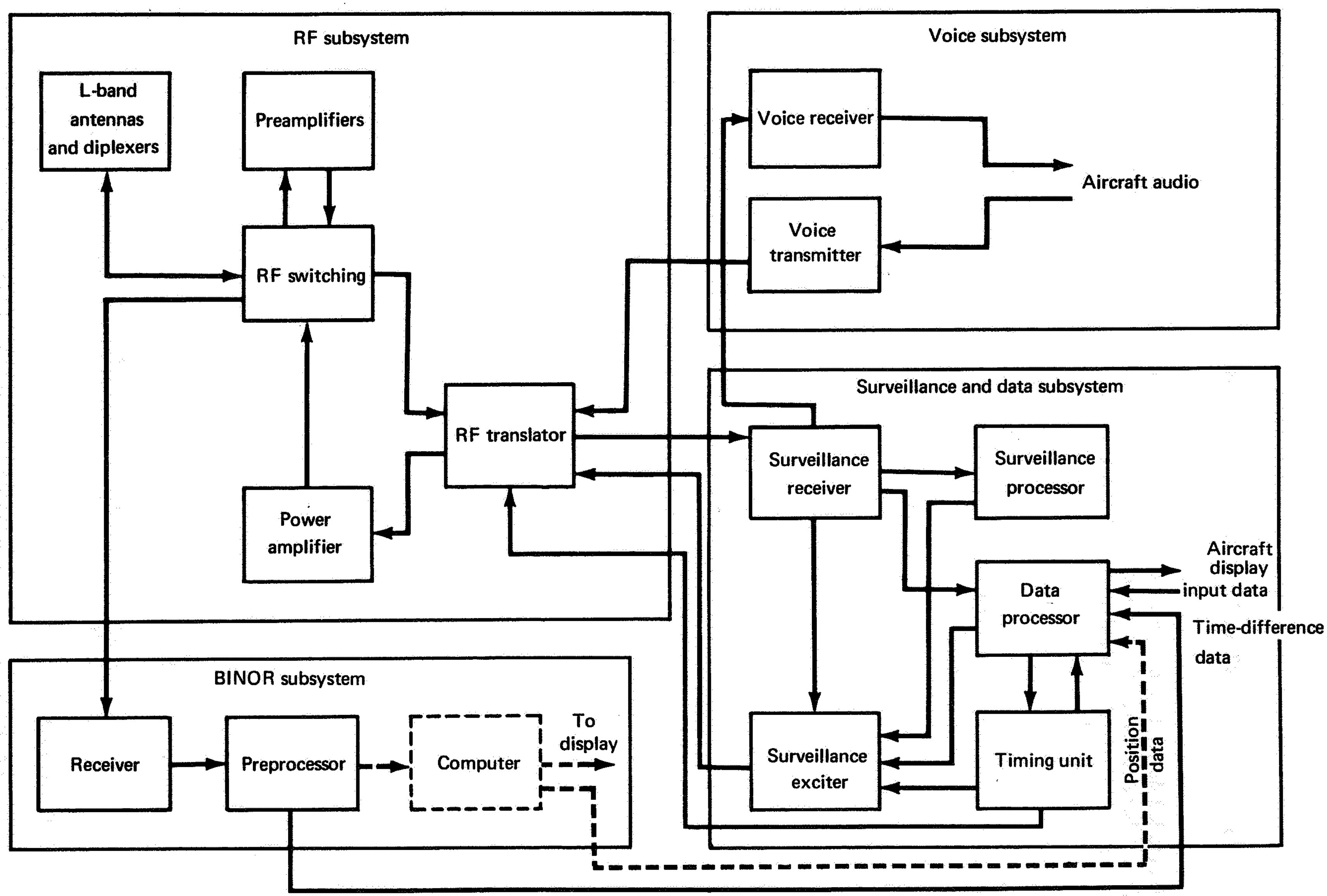

FIGURE 7.– AIRCRAFT EXPERIMENTAL - TERMINAL FUNCTIONAL DIAGRAM

(5) Permit translation to and from i.f. and routing of all voice and surveillance signals to and from the applicable subsystems

(6) Provide adequate rf power amplification of the return voice and surveillance signals

3.1.2 Surveillance and data subsystem. - The requirements and constraints under which the surveillance and data subsystem of the experimental terminal operates are detailed in the following. Since both tone and BINOR surveillance schemes may be used, the system requirements for each method are discussed individually.

For a surveillance system using the continuous-tone scheme discussed in Sec. 3.1 of vol. III, the surveillance and data subsystem is required to:

(1) Receive and coherently demodulate the forward-link surveillance carrier

(2) Demodulate the PCM/PSK data subcarrier, and establish bit and frame synchronization

(3) Initiate the turnaround tone surveillance response sequence when the correct aircraft address code is received and detected

(4) Detect, from the received message, the surveillance extended response command, if present, and modify the response sequence

(5) Detect, from the received message, voice status information and provide it to the voice channel status display in appropriate format

(6) Filter the ranging tones from the received baseband and provide the output to the surveillance exciter for retransmission

(7) Coherently convert the received surveillance carrier frequency by a specified ratio for use as an rf carrier for the surveillance response

(8) Generate the return data subcarrier and PCM/PSK modulate it with synchronization, aircraft address, digitized altimeter measurement, and voice channel requests, as required

(9) Phase modulate the return carrier with the filtered tones and the data subcarrier, and amplify the i.f. signal for input to the rf translator

(10) Provide carrier reference for the voice subsystem

The operation of the surveillance and data subsystem using a BINOR scheme involves the interrogation and response of the aircraft in conjunction with the ground ATC center. This is done in the same way as for the tone surveillance scheme, with the exception that only the carrier and data channel are present, since no tones are transmitted. The requirements and constraints of the subsystem for such a scheme are therefore identical to those enumerated above for the tone surveillance scheme, except for items (3), (6), (8), and (9). Item (6) is not applicable; items (3), (8), and (9) are revised to require the system to:

(1) Initiate the surveillance response sequence when the correct aircraft address code is received and detected

(2) Generate the return data subcarrier and PSK modulate it with synchronization, aircraft address, BINOR data (time-difference or position), altimeter measurement, and voice channel requests, as required

(3) Phase modulate the return carrier with the data subcarrier and amplify the i.f. signal for input to the rf translator

3.1.3 Voice subsystem. - The voice subsystem of the experimental terminal is required to:

(1) Receive and demodulate the forward-link narrowband-FM voice signal

(2) Provide signal conditioning and sufficient amplification of the received baseband voice signal to obtain compatibility with voice-link audio equipment aboard the aircraft

(3) Accept the voice baseband for the return link from the aircraft audio equipment, and incorporate the necessary signal conditioning for modulation on the return-link carrier

(4) Generate the return-link carrier with a free-running onboard local oscillator, modulate the carrier in a narrowband-FM scheme, and provide i.f. amplification to the required level for presentation to the rf translator

3.1.4 BINOR subsystem. - For a surveillance system employing a BINOR scheme, as discussed in Sec. 3.2 of vol. III, the experimental terminal would be configured differently from one using the tone system alone. The primary change is that the terminal would be augmented with the BINOR subsystem, in addition to having the surveillance and data subsystem, used for the interrogation and response of the aircraft for surveillance, simplified slightly by the absence of the tone turnaround processing requirement. The BINOR subsystem is composed of the BINOR receiver, preprocessor, and possibly an onboard computer, the requirements and constraints of which are described fully by system contractor TRW in ref. 6.

The subsystem is further required to provide to the data processor of the surveillance and data subsystem the response data to be transmitted to the ATC center upon interrogation in the surveillance process. The data are of two types: either unprocessed time-difference data from the received satellite BINOR transmissions or aircraft position data derived from the received signals and processed by the onboard computer. The data are presented in digital form to update a storage register in the data processor whenever a new set of time-difference or position data is obtained.

3.2 RF Subsystem

As seen in fig. 7, the rf subsystem includes the antennas, preamplifiers, rf translator, power amplifier, and rf switching of the experimental terminal. Transmitter power and antenna gain parameters of the rf subsystem will vary, because of the possibility of different satellite configurations, so that initial tradeoffs must be performed. The terminal characteristics are thus considered first from parametric tradeoffs, after which a detailed description of the proposed rf subsystem and its components is made.

3.2.1 Satellite/aircraft parameter tradeoffs.– To obtain the required performance of the voice and surveillance links in the L-band SST/satellite system, a tradeoff exists among the transmitter powers and antenna gains at the satellite and aircraft terminals. A parametric representation of these parameters was developed for the surveillance and voice analysis of vol. III, since the characteristics of the satellite terminal will not be known until further decisions concerning satellite availability for the experimental program are made. The present approach in defining an experimental terminal, therefore, is to assume the availability of satellite transmitter power and antenna gain at several different levels, within state-of-the-art limitations. Based on these satellite parameters, the corresponding terminal requirements are determined and the aircraft experimental terminal configuration defined.

Several alternate satellite configurations are proposed for possible extremes in satellite EIRP (effective isotropic radiated power, the product of total transmitter power and antenna gain divided by rf circuit loss), with transmitter powers from 10 watts to 75 watts and antennas from earth coverage to coverage of an area 1000 n.mi. or less in diameter. These alternates are listed in table 10.

Alternate 1 represents present-day L-band capability, with 10 watts of repeater power and an earth-coverage antenna pointed to local vertical, i.e., the center of the earth. Alternate 2, the next level of satellite development, represents capabilities for the early 1970's, with greater total repeater powers of from 20 watts to 75 watts and a more sophisticated regional-coverage antenna, which has 6 dB greater peak gain than the earth-coverage antenna and is capable of being pointed to the center of the desired North Atlantic coverage area. Regional-coverage, narrow-beam satellite antennas are within the present state of the art, as evidenced by the planned replacement satellites for the Interim Defense Communication Satellite Program (IDCSP), which will be implemented with antennas having 1000- to 2000-mile regional-coverage areas (12-dB to 18-dB greater gain than earth-coverage). Alternate 3 as proposed represents a later-generation satellite incorporating a 75-watt or greater repeater power and multiple-beam, area-coverage antenna capability with beamwidths of about 1° to 3° for illumination of areas of several hundred to one thousand n.mi. in diameter. Area-coverage capability could typically be implemented with the APPA (Artificial Pilot Phased Array) technique discussed in Sec. 9.1 of vol. IV. Current information on ATS-F and G designs shows that a 30-foot antenna is planned, which would provide EIRP's consistent with satellite alternate 2 and 3 levels.

The aircraft transmitter power and antenna gain requirements for each of the alternate configurations of table 10 can now be considered. First, surveillance and voice functions for each alternate are considered individually in terms of the antenna gain and transmitter power requirements imposed on the aircraft terminal. The requirements are then combined to define an integrated experimental terminal having both capabilities. The integrated approach is desirable since several components of the terminal are used by both voice and surveillance functions, in particular the power amplifier, antennas, preamplifiers, and receiver and exciter rf sections.

TABLE 10.–SATELLITE CONFIGURATION ALTERNATES

Alternate	Transmitter power	Antenna	EIRP, dBW (d)
1	10 W	Earth coverage[a]	+24.1
2	20 to 75 W	Regional coverage[b]	+34.9 to +40.6
3	75 W	Area coverage[c]	+52.2

[a]Peak gain = +19.6 dB; edge gain, including pointing losses = +15.6 dB

[b]Peak gain = +25.6 dB; edge gain = +23.4 dB

[c]Edge gain ≈ +35 dB; 2.8° HPBW, 1100-n. mi.-diameter area

[d]Includes 1.5 dB of rf circuit loss

From the link performance analysis for the surveillance and voice links in Secs. 3.0 and 8.0, respectively, of vol. III, the tradeoffs between satellite and aircraft parameters are determined. Table 11 presents the aircraft terminal requirements for the three satellite configuration alternates. The data shown were derived from the worst-case performance graphs of fig. 13 of vol. III for surveillance and figs. 99 and 102 of vol. III for voice performance. Requirements for both a solid-state (transistor) and an uncooled paramp aircraft preamplifier are considered in table 11. The paramp is presented as a possible implementation for the experimental terminal, where limited satellite capability may have to be compensated for with the improved noise performance of the paramp. The operational system, on the other hand, would incorporate the transistor preamplifier recommended (Sec. 2.4) on the basis of cost, reliability, and maintainability. The data for a paramp implementation are obtained by modifying the earlier performance graphs by an improvement factor of 4.5 dB. Considered with this adjustment is the need to raise the aircraft's transmitter power correspondingly when the antenna gain is reduced with the use of the paramp. The requirements for surveillance capability are shown for the tone-surveillance scheme; for BINOR surveillance capability the requirements change somewhat. For links between the aircraft and ATC center, over which interrogation and response for each aircraft are performed, the BINOR requirements are reduced slightly (5 dB) for the forward (ATC-to-aircraft) links, but are about the same as those of the tone system for the return (aircraft-to-ATC) links, as discussed in Sec. 3.2.2 of vol. III. These requirements are, however, additional to those required for the prime satellite-to-aircraft (NAVSTAR) navigation links over which each aircraft receives the BINOR transmission for determination of position. To determine the power and gain requirements of the experimental aircraft terminal, the tone scheme will be considered, with the understanding that the BINOR scheme can also be accommodated within these capabilities, assuming the additional implementation of NAVSTAR capability at the satellites and aircraft.

Voice-link requirements shown in table 11 are for both single and multiple channels, depending on satellite configuration. Alternate 1 and the lower transmitter power capability (20 watts) of alternate 2, for example, assume single-channel voice transmission, whereas the 75-watt capability of alternate 2 and alternate 3, more suitable for an operational system,

TABLE 11.—AIRCRAFT EXPERIMENTAL-TERMINAL REQUIREMENTS

Satellite			Aircraft				
				Surveillance		Voice	
Config. alternate	Total transmitter power/ antenna	EIRP, dBW	Preamp device	Antenna gain, dB	Transmitter power, W	Antenna gain, dB	Transmitter power, W
1	10 W/earth coverage[a]	+24.1	Transistor	+5.2	165	+18.0	19
			Paramp	+0.7	475	+13.5	55
2	20 W/regional coverage[b]	+34.9	Transistor	-1.0	110	+ 8.0	27
			Paramp	-1.0	110	+ 3.5	80
	75 W/regional coverage[c]	+40.6	Transistor	-1.0	110	+ 8.0	54
			Paramp	-1.0	110	+ 3.5	160
3	75 W/area coverage[c]	+52.2	Transistor	-1.0	7.5	- 1.0	32
			Paramp	-1.0	7.5	- 1.0	32

[a]Nonsimultaneous repeater operation: surveillance or single-channel voice

[b]Simultaneous operation: surveillance and single-channel voice

[c]Simultaneous operation: surveillance and three-channel voice

assumes three-channel voice capability. Should only moderate satellite capability be available, a single-voice-channel experimental terminal would be more feasible; however, if sufficient satellite capability were provided, a demonstration of a three-channel operational-type terminal could be made.

In determining aircraft terminal requirements, it is assumed that the satellite power available is used for both surveillance and voice functions simultaneously, i.e., that the combined power of the satellite voice and surveillance repeaters is equal to the value shown. This approach is not permitted for the alternate 1 satellite, however, where low EIRP permits only one transmission function at a time.

As shown in table 11, for surveillance capability an alternate 1 type satellite with a transistor preamplifier at the aircraft requires a +5.2-dB aircraft antenna gain and a 165-watt aircraft transmitter for the reply link. If an uncooled paramp were used at the aircraft, the reduction in aircraft antenna gain to +0.7 dB would increase the transmitter power required for the return link to 475 watts, which would require more prime power ($\sim$ 2 kW) than desired at the aircraft terminal. An alternate 2 type satellite, on the other hand, requires only a -1-dB antenna gain and a transistor preamplifier at the aircraft in conjunction with a transmitter power of 110 watts. An antenna gain of -1 dB with hemispherical coverage (above 10° elevation angle) can be implemented with moderate development effort, as determined from pattern measurements discussed in Sec. 3.0 of vol. IV. Only 6 watts of satellite power are required for the surveillance with a -1-dB antenna, leaving 14 watts for the voice repeater. Use of a paramp in the alternate 2 case is not warranted for surveillance capability alone, since further antenna-gain reduction is not needed. It is thus seen that a paramp would be of questionable value from consideration of the surveillance link alone, since for alternate 1 the aircraft transmitter power may be excessive, while for alternate 2 the reduction in antenna gain is not required. From surveillance-link considerations, therefore, alternate 1 with +5.2-dB aircraft antenna gain and a transistor preamplifier, or any of the other alternates with a -1-dB aircraft antenna and transistor preamplifier, provides satisfactory performance.

Satisfactory performance of the voice links, as seen in table 11, requires substantially higher satellite EIRP and/or aircraft antenna gain. The minimum-capability satellite, alternate 1, for example, requires +18 dB of aircraft antenna gain for threshold performance of an experimental single-channel voice link using a transistor preamplifier. The use of a paramp still requires a +13.5-dB aircraft antenna gain. Alternate 2, on the other hand, with 14 watts available for the voice repeater, requires only +8-dB antenna gain using a transistor preamplifier and +3.5-dB gain using a paramp for single-channel voice capability. Should the upper limit of satellite transmitter power (75 watts) be available for alternate 2, the surveillance repeater would again require only 6 watts, leaving 69 watts for the voice repeater. For this case, a three-channel, operational-system voice capability could be demonstrated, with about the same aircraft antenna gains as for the single channel. For an alternate 3 satellite capability, required aircraft antenna gain is minimal for a three-channel operational-type system; a -1 dB gain figure is again assumed as a realizable value over the upper hemisphere of the aircraft.

Required aircraft transmitter power for voice-link operation is acceptable with all satellite alternates, assuming use of the same aircraft antenna for reception and transmission. From table 11, the maximum requirement is 160 watts for a three-channel system and an alternate 2 satellite. Required aircraft transmitter power is increased by 3 dB over the single-channel case for a multichannel system, as discussed in Sec. 8.3.2 of vol. III.

A discussion of aircraft antenna systems that will meet the gain requirements listed in table 11 is presented in Sec. 7.0 of vol. IV. A two-dimensional array with beam steering in two dimensions is necessary to satisfy gain requirements greater than +10 dB. A linear array with fixed multiple beams or simplified beam steering will satisfy gain requirements from +6 dB to +10 dB. Fixed-beam antennas can be used for gains less than +6 dB for the experimental terminal that demonstrates a New York-London track capability.

As is apparent from aircraft antenna requirements, an alternate 2 type satellite is preferable for the experimental program. If an alternate 1 type satellite, of limited EIRP, is all that is available, aircraft antenna gains of +13.5 or +18 dB will be required, necessitating a rather complex phased-array implementation. Not only would such an antenna be expensive to develop and implement for the experimental phase of the program, it also would not be representative of the operational system, since for that phase a higher-EIRP satellite would probably be available and moderate antenna gain requirements could be realized at the aircraft. In addition, an alternate 1 satellite would not permit simultaneous performance of voice and surveillance functions, such as would occur in an operational system, since low satellite power constrains usage to only one function at a time. Some relief is possible from gain requirements by using a paramp preamplifier at the experimental terminal, and would result in a performance improvement of 4.5 dB. If sufficient satellite EIRP is not available, however, more complex, higher-gain aircraft antennas will have to be implemented for the experimental testing.

As seen from table 11, aircraft terminal transmitter power and antenna gain are excessive for an alternate 1 (10 watt/earth-coverage) satellite capability. System tests with such a satellite are seen to require +13.5 dB to +18.0 dB aircraft antenna gain and a transmitter power approaching 500 watts. Even with this capability, however, experimentation is limited to surveillance and single-channel voice demonstrations. Since it is desirable to demonstrate as far as possible the performance characteristics of an operational system, the proposed experimental aircraft terminal is configured assuming the availability of at least the lower capability of an alternate 2 satellite, i.e., 20 watts total transmitter power and a regional-coverage antenna. Should a full-capability alternate 2 satellite (75 watts) be available, even further experimental capability would exist.

3.2.2 Functional description. - Definition of the recommended rf subsystem for the aircraft experimental terminal may now be made on the basis of the antenna gain and transmitter power parameters of table 11. As mentioned, the rf subsystem incorporates both voice and surveillance functions, with sharing of antennas, preamplifiers, power amplifier, and rf translator. Usage of common components is desirable for an operational system, where constraints of cost and simplicity lead to such a terminal, particularly since equipment requirements for voice and surveillance functions overlap substantially. Surveillance response from the aircraft is in the form of a 1-second reply occurring only once every 3 minutes. Since, in an operational system, voice communication from an individual aircraft is infrequent, it is possible to have the surveillance response share the same power amplifier with the voice links. To reduce power requirements, it is recommended that an override capability exist in the rf translator, with the surveillance response overriding the voice response when the surveillance reply is made. Antenna sharing is a somewhat different problem, in that the voice link operates through only one satellite; whereas the tone surveillance system must operate through two, at least for the return link. The BINOR surveillance scheme requires antenna coverage in the direction of all satellites (three or four) from which the initial BINOR code is emitted to the users. Even though multiple satellites may not be available for the experimental program, the capability should exist on the aircraft for sufficient gain in the direction of all satellites, so that operational system coverage capability can be demonstrated. Antenna sharing, therefore, may be feasible only where similar gain requirements exist for both functions.

The proposed experimental terminal rf subsystem is illustrated in the block diagram of fig. 8. As seen, maximum flexibility is provided to demonstrate and test all required system functions under a variety of terminal component implementations. This flexibility is obtained by providing several aircraft antennas, together with two possible preamplifier devices and a power amplifier with variable attenuation input power control, to demonstrate the various voice and surveillance functions.

The aircraft parameters of antenna gain (for the directional antennas) and transmitter power associated with the proposed terminal in fig. 8 are dependent upon which satellite capability is available. For minimum alternate 2 capability, a +8-dB antenna implementation and 110-watt power amplifier are used, while for the maximum alternate 2 capability, a +3.5-dB antenna and a 160-watt power amplifier are provided. In each case, a low-gain (-1 dB, hemispherical-coverage) antenna and both transistor and paramp preamplifiers are also present.

The proposed terminal will be able to:

(1) Demonstrate forward and return surveillance via the -1-dB low-gain antenna (LGA) and transistor or paramp preamplifier

(2) Demonstrate two-way, single-channel voice via directional antenna and transistor or paramp preamplifier

(3) Demonstrate two-way, three-channel voice via directional antenna and paramp preamplifier

(4) Demonstrate simultaneously both surveillance and single-channel voice via directional antenna and paramp preamplifier

(5) Demonstrate simultaneously both surveillance and three-channel voice via directional antenna and paramp preamplifier

(6) Permit testing of multichannel voice performance for both balanced power ratios and various strong/weak signal combinations in the satellite repeater to determine the effects on system performance

(7) Permit testing of intermodulation degradation effects in the satellite repeater for three-channel operation

For a maximum-power (75 watt) satellite, the terminal would incorporate lower-gain (+3.5 dB) directional antennas and a slightly larger power amplifier to compensate for the reduced antenna gain. The capabilities of such a terminal would be identical to those enumerated above, with the addition of the ability to:

(8) Demonstrate two-way, single-channel voice via the LGA and paramp preamplifier

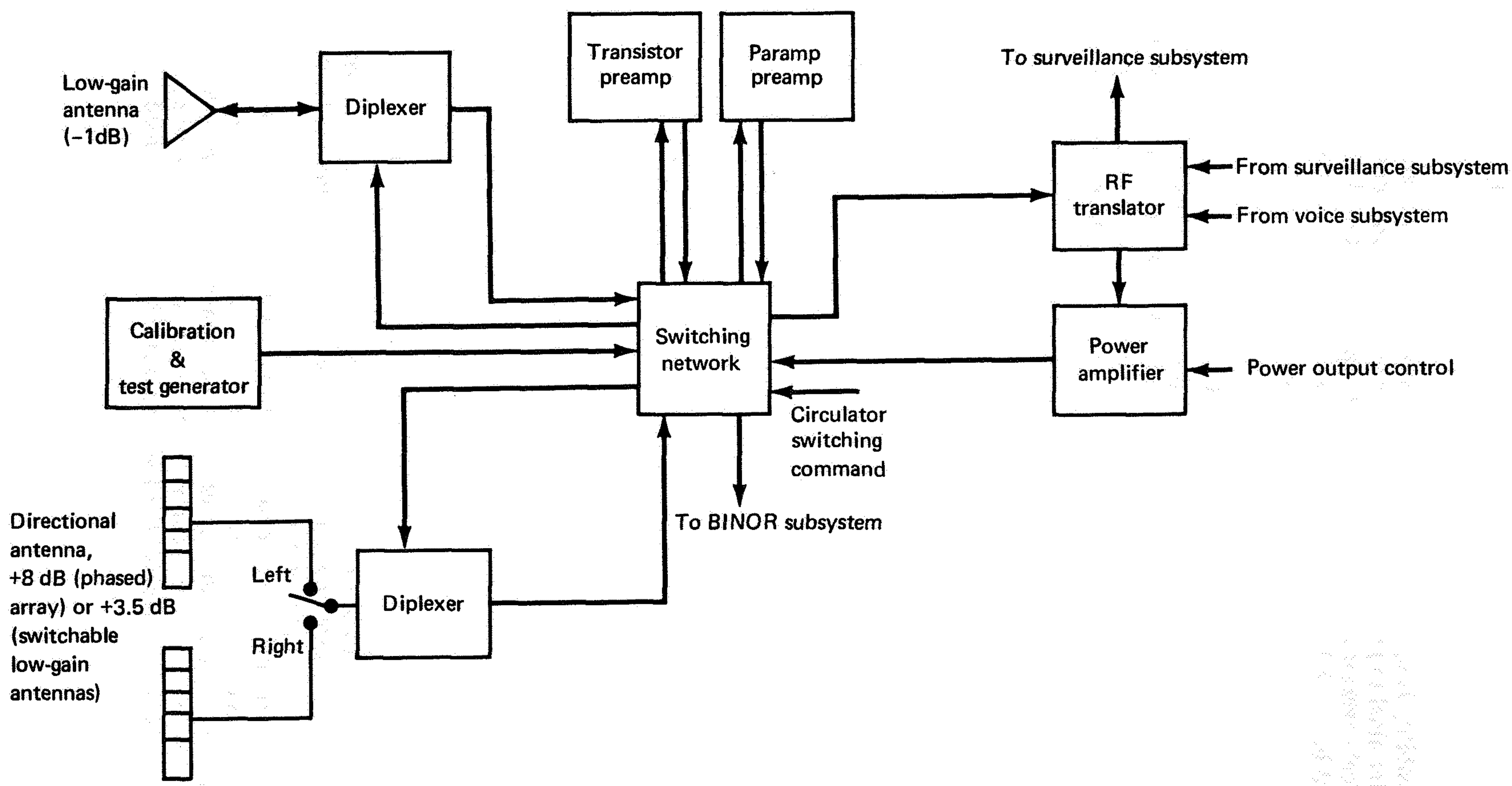

FIGURE 8.– RF SUBSYSTEM FOR EXPERIMENTAL AIRCRAFT TERMINAL

(9) Demonstrate simultaneously both surveillance and single-channel voice via the LGA and paramp preamplifier

This final capability is significant in that it represents the ultimate aim of the operational aircraft terminal to provide both surveillance and voice functions over a single low-gain, hemispherical-coverage antenna at the aircraft. In an operational system, in addition, such capability would be realizable with a transistor preamplifer at the aircraft terminal and a multichannel mode of voice operations, with the required link margin being accommodated by greater satellite EIRP.

The power amplifier level in each configuration is provided for the worst-case transmitting requirement, with a variable attenuation capability provided to reduce the transmitted power when lower levels are desired for performance testing. With the minimum-power regional-coverage satellite, a 110-watt aircraft transmitter power is provided, since this level is required (table 11) for surveillance response transmission over a -1-dB antenna to a regional-coverage satellite antenna. Required transmitter power for voice communication, even in a three-channel system, is less than 110 watts. With the maximum-power satellite, the maximum required transmitter power is 160 watts, with a +3.5-dB aircraft antenna gain and regional-coverage satellite antenna for a three-channel voice system.

Both a transistor and a paramp preamplifier are incorporated into the experimental terminal to demonstrate various system capabilities. The paramp provides a +4.5 dB improvement in system noise performance. The switching functions performed by the rf switching network are necessary for connecting the various components of the rf subsystem for performance testing. Switching functions are not necessarily performed with mechanical and electrical switching, since for testing purposes the desired combination of components can be hard-wire connected prior to each test, thereby minimizing rf losses between components. The capability for switching, or interconnection, will exist for:

(1) Switching between antennas (left or right) of the directional-beam antenna configuration (+3.5-dB or +8-dB gain)

(2) Routing of either antenna input (low-gain or directional) through either preamplifier (transistor or paramp) to the rf translator

(3) Connection of calibration and test generators to all devices in the terminal

(4) Routing of the power amplifier output to either antenna (low-gain or directional) for transmission

This last requirement also covers simultaneous surveillance and voice demonstration, when it is desired to route the surveillance response to the low-gain antenna and the voice to a directional antenna. Since the power amplifier output is used for both functions, with the surveillance reply overriding the voice to obtain full transmitter power for the 1 second during which the aircraft is under surveillance, a fast-response device is required as part of the switching implementation to permit this feature. It is recommended that a switching circulator device be used, with switching controlled by input commands generated in the surveillance and data subsystem whenever the 1-second surveillance reply is made.

After routing of a received signal (or signals, when voice and surveillance are demonstrated together) through either the transistor or paramp preamplifier, the preamplifier output is routed to the rf translator, where translation is made to i.f. for the voice and/or surveillance signals. The i.f. output is then routed to the surveillance and data subsystem for further down-conversion and subsequent demodulation in the surveillance and data or voice subsystems. For the return voice and surveillance links, the output from the rf translator is provided to the power amplifier and then routed via appropriate switching to the desired antenna for transmission. For the case of simultaneous voice and surveillance demonstration, with the surveillance response being transmitted over the low-gain antenna and the voice transmitted over the directional antenna, the switching implementation incorporates a switching circulator or similar device. The power amplifier output is thereby routed to the appropriate antenna. The 1-second surveillance response is thus transmitted over the low-gain antenna and the voice response, during the remainder of the time, over the directional antenna.

The major components of the rf subsystem are now discussed in greater detail in terms of their operation and required performance characteristics. These include the antennas and diplexers, preamplifiers, power amplifier and attenuator, and rf translator.

In addition, signal and test generators will be included in the terminal to calibrate the system for signal-level measurements and to monitor system performance. The test generator will provide the terminal with simulated surveillance and data signals for checkout of the rf, surveillance and data, and BINOR subsystems, as well as supply tone-modulated signals for voice-subsystem checkout.

3.2.2.1 Antennas: The recommended antenna system for the experimental terminal consists of low-gain and medium-gain antenna systems which can be switched. The low-gain antenna system consists of a single circularly-polarized top-mounted antenna similar to the orthogonal-mode cavity shown in fig. 9. The antenna is 6 inches in diameter with a depth of about 3 inches. The maximum gain of the antenna is +6 dB and the 3-dB beamwidth is 110°. The antenna is described in detail in Sec. 3.2 of vol. IV.

If the 20-watt satellite is used, Butler-matrix-fed fixed multiple-beam arrays of dielectric-loaded orthogonal-mode cavities that provide from 7 to 12.3 dB gain flush-mounted on the side of the fuselage are recommended. The arrays are 6 by 33 by 4 inches.

If the 75-watt satellite is used, the medium-gain system can be simplified to two-element nonsteerable arrays of dielectric-loaded cavities that will provide +3.6-dB gain and sufficient multipath discrimination throughout the required coverage volume. The arrays are mounted so that the antenna normal points 38° above the horizon. The antennas would be 6 by 10 by 4 inches. The two-element array is discussed in detail in Sec. 7.2 of vol. IV.

3.2.2.2 Preamplifiers: Two low-noise preamplifiers, one a transistor type and one a paramp, are used for preliminary amplification of the received forward signals at the aircraft terminal before routing to the rf translator for down-conversion and subsequent demodulation. The two available types of low-noise amplifier devices used at the terminal provide flexibility in demonstrating system performance with different antennas in a variety of operational modes.

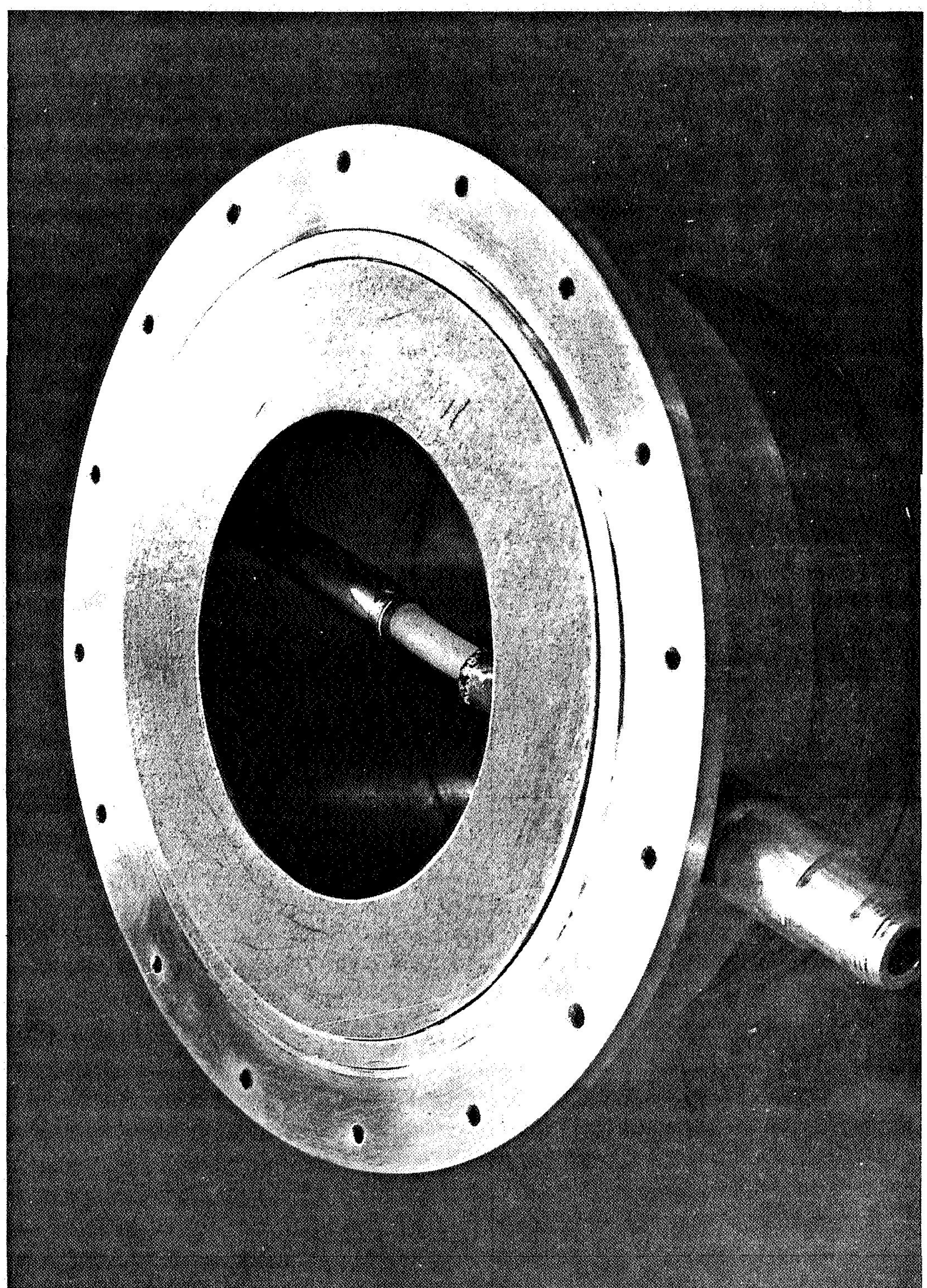

FIGURE 9.– ORTHOGONAL-MODE CAVITY ANTENNA

Discussion of state-of-the-art devices for L-band low-noise preamplifiers is covered in Sec. 2.4, where it is concluded that the transistor preamplifier represents the best compromise for the operational system in terms of availability, low-noise performance, and cost. However, for the experimental phase where satellite power is limited, an uncooled-paramp preamplifier was selected as an added implementation at the terminal (since a noise-performance advantage of about 4.5 dB is realized).

Should the optimum antenna positions on the aircraft cause the mounting of the antennas far from the main equipment compartment (so that rf line loss between the antennas and compartment becomes excessive), it is recommended that the preamplifiers and rf switching be placed out of the equipment compartment as near to the antenna as is feasible. In this way, line loss between antennas and preamplifier will be minimized, resulting in improved reception of the incoming signals. The disadvantages of placing the preamplifier outside of the equipment compartment include greater environmental variations in temperature and pressure and more difficult maintenance. Neither of these factors is extremely significant; a transistor amplifier could be packaged to withstand the expected environmental limits outside the compartment, and its high reliability should result in infrequent servicing of the unit. Paramp devices (during the experimental program) can be placed inside the cabin area adjacent to the antennas. This permits controlled environmental conditions and ready access for servicing and test measurements. In the operational phase of the program, sufficient satellite power would be available to permit use of a transistor preamplifier alone. The transistor preamplifier might be integrated into the antenna feed for maximum reliability and performance advantage.

The performance of both the transistor and paramp preamplifiers is summarized by the parameters of table 12.

The paramp preamplifier, for full realization of its low-noise performance, is to be followed immediately by a transistor amplifier with characteristics similar to those specified in table 12 for the transistor preamplifier. The transistor second stage would be an inherent part of the preamplifier unit and would provide the required additional gain and low-noise performance needed to obtain maximum performance capability from the paramp device.

TABLE 12.– EXPERIMENTAL-TERMINAL PREAMPLIFIER PARAMETERS

Parameter	Transistor	Paramp
Center frequency	(a)	(a)
Bandwidth, 1 dB	5 MHz	5 MHz
3 dB	20 MHz	20 MHz
Noise temperature	450°K	50°K
Noise figure	4.07 dB	0.69 dB
Gain	+20 ±1 dB	+17 ± 1 dB

[a] To be specified; within the 1540-1560 MHz band

3.2.2.3 Power amplifier: A single power amplifier is required for the experimental terminal, to be used for both voice and surveillance functions, with the surveillance response receiving full power for its 1-second duration. Sufficient power is provided by the amplifier to accommodate whichever function is the limiting one, so that each function in conjunction with the appropriate antenna configuration produces sufficient aircraft EIRP for satisfactory link performance. The required transmit power (as determined in the tradeoff analysis of Sec. 3.2.1), is either 110 watts or 160 watts, depending on whether 20 watts or 75 watts of satellite power are available.

A survey of applicable L-band devices for power amplification (see Secs. 2.1 and 2.4) concludes that a traveling-wave-tube (TWT) power amplifier, in a saturated mode of operation, is the best choice for the power levels required. Other devices, notably klystrons and crossed-field devices, show potential for the power levels and frequency band required; but, they would require significant development effort for application to the operational terminal. Similarly, solid-state devices might be developed for lower power levels, but they are not feasible for the experimental phase where limited aircraft- and satellite-antenna gains require higher power devices than might be utilized in an operational system.

TWT amplifiers are presently available in the L-band region with power levels up to 1 kW. Physical dimensions and weight are higher than usual for avionics equipment; consequently some modification would be necessary, particularly for the operational system where weight would be a highly critical factor. TWT efficiencies require improvement for terminal usage, since overall efficiencies (rf power/input power) must be improved, from 15%, to 25% or better to be practical. This improvement becomes possible by using depressed-collector and narrowband techniques.

The power amplifier unit for the experimental terminal includes the TWT device, a power supply, and the required variable-attenuation device needed to reduce power output to lower levels for various experimental operations. The power supply converts the available aircraft prime power (400-Hz three-phase ac power at 208 volts) to the required dc level for operation of the TWT. Power supply efficiencies of 85% are realizable. The variable attenuator is adjustable manually attenuating the input signal to result in "backed-off" linear TWT operation. Capability is also provided to monitor and measure power output.

The required characteristics of the TWT power amplifier unit are summarized below:

Center frequency	to be specified, within the 1640- to 1660-MHz band
Bandwidth, 1 dB	10 MHz
RF power output	110 watts or 160 watts (worst case)
Saturated gain	30 dB minimum
Tube efficiency	30% design goal for operational terminal
Power supply efficiency	85% minimum
Overall efficiency	25.5% design goal for operational terminal

3.2.2.4 RF translator: As the majority of signal processing is done at much lower frequencies than L-band—i.e., in the surveillance and data, and voice subsystems—some means of translating the L-band received signal to a lower frequency in the VHF range and of multiplying the transmit signals from VHF to L-band must be provided. These functions are accomplished in the rf translator. A block diagram of the rf translator is given in fig. 10. In discussing the terminal operation, a typical set of assigned frequencies has been postulated and these frequencies are used to clarify the different subsystem functional descriptions. The frequencies are as follows:

Forward surveillance carrier . . . . 1553.75 MHz

Return surveillance carrier . . . . 1650.0 MHz

Forward voice carrier:

Channel 1 . . . . 1555.1 MHz
Channel 2 . . . . 1555.2 MHz
Channel 3 . . . . 1555.3 MHz

Return voice carrier:

Channel 1 . . . . 1652.0 MHz
Channel 2 . . . . 1652.1 MHz
Channel 3 . . . . 1652.2 MHz

The down-converter, following the preamplifiers, includes the first mixer, the multiplier for oscillator injection to the first mixer, and the first i.f. amplifier. The injection frequency to the first mixer is chosen such that the image frequency for the first mixer is in the protected 1420- to 1427-MHz radioastronomy band, thereby ensuring that no undesired signals from ground, air, or spaceborne transmitters will enter the system. This relaxes the image-suppression requirements to the point where only the image-noise contribution must be considered. The 1485-MHz signal will be derived from the VCO in the surveillance receiver followed by a multiplier chain providing approximately 10 mW output.

The resulting i.f. output, containing both surveillance/data and voice signals, is amplified by the first i.f. amplifier. This amplifier provides approximately 100-dB gain near 70 MHz over a band wide enough to include both voice and surveillance signals (68.75 MHz to 70.3 MHz in the example shown). The output from the i.f. amplifier is routed to the surveillance receiver where the voice and the surveillance/data signals are ultimately separated.

The transmitter driver/multiplier includes the necessary power amplification to drive the power amplifier and multiplies the VHF angle-modulated signal to L-band. It is used in both the surveillance and voice modes. Appropriate switching is built into this unit to allow the surveillance/data signal to override the voice signal, and at the same time to alert the operator with an aural indication that his voice transmission is cut off during the 1-second surveillance/data burst.

The surveillance-response signal arrives at the rf translator in the VHF range (110.0 MHz in the example) and is routed to the data-transmit enable gate. It is allowed to pass to the driver/frequency multiplier stage whenever a data key signal is received from the surveillance and data subsystem. The voice signal also reaches the rf translator in the VHF range

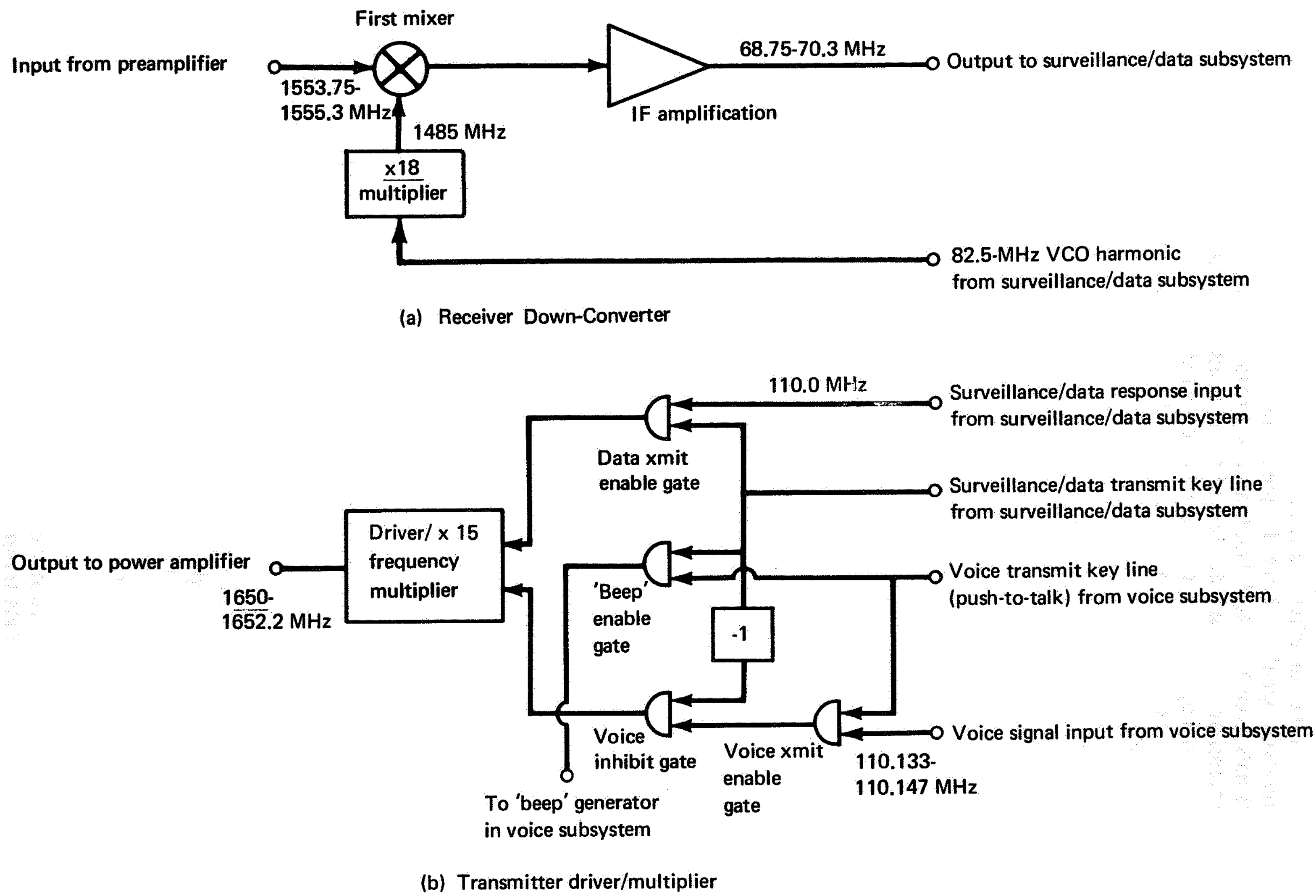

FIGURE 10.– RF TRANSLATOR BLOCK DIAGRAM

(110.133 to 110.147 MHz for the three voice channels in the example). It passes through the voice-transmit enable gate whenever the push-to-talk is operated. It is allowed to pass to the driver/frequency multiplier whenever the voice inhibit gate is enabled by lack of a surveillance/data transmit key signal. The previously described switching functions provide the necessary override for the surveillance response signal. An additional gate, the "beep" enable gate, provides an output to the voice receiver whenever the surveillance response signal overrides the voice signal, thereby alerting the operator that his voice transmission was momentarily cut off.

Both the voice and surveillance signals are amplified and frequency multiplied in the driver/frequency multiplier section. The actual frequency multiplication scheme may include a mix of amplifiers and multipliers, such as a power amplifier followed by a times-five multiplier, followed by further power amplification and a times-three multiplier. The output of the driver/frequency multiplier is filtered to remove the undesired spurious and harmonically related signals and is then routed to the power amplifier. It is estimated that the input power requirement for the signals from the voice and surveillance exciters will be approximately 100 mW to 500 mW at VHF, and that the L-band output will be on the order of 1 watt.

3.3 Surveillance and Data Subsystem

A functional description of the surveillance and data subsystem is provided in the following paragraphs, with the subsystem providing capability for terminal operations with either the multiple-tone or the BINOR surveillance implementations. Subsystem operations for the tone scheme are discussed first, after which description for a BINOR implementation is presented. The changes due to the BINOR scheme are slight, since capability must still exist in the subsystem for interrogation of the aircraft by the ATC center and formulation and transmission of the aircraft reply so that surveillance of all aircraft can be maintained. The major change for the BINOR scheme is the removal of tone processing capability in the subsystem and the addition of the BINOR subsystem (receiver, preprocessor, and possibly a computer).

A block diagram of the surveillance and data subsystem is shown in fig. 11. Operations with the tone surveillance scheme are described first, after which modifications for BINOR surveillance are treated.

3.3.1 Tone surveillance. - As seen in fig. 11, the surveillance and data subsystem is comprised of five components for operation with a tone surveillance scheme: a receiver, surveillance processor, data processor, timing unit, and exciter. The receiver coherently tracks and demodulates the carrier and demodulates the data subcarrier. The surveillance processor filters the received tones for turnaround transmission. The data processor decommutates the received data, detects the aircraft address code, and formats the surveillance reply data. The timing unit actuates and sequences the aircraft response when the correct address code is received. The exciter converts the received carrier for return transmission and remodulates it with the turnaround tones and the return-data subcarrier. Each component is now discussed in detail for surveillance operation.

3.3.1.1 Surveillance receiver: The surveillance receiver, shown in detail in fig. 12, accepts from the rf translator all received signals at i.f., performs further down-conversion, and tracks coherently and demodulates the forward surveillance signal. The received i.f. band, from 68.75 MHz to 70.3 MHz in the example, is mixed down to the 12.2- to 13.75-MHz

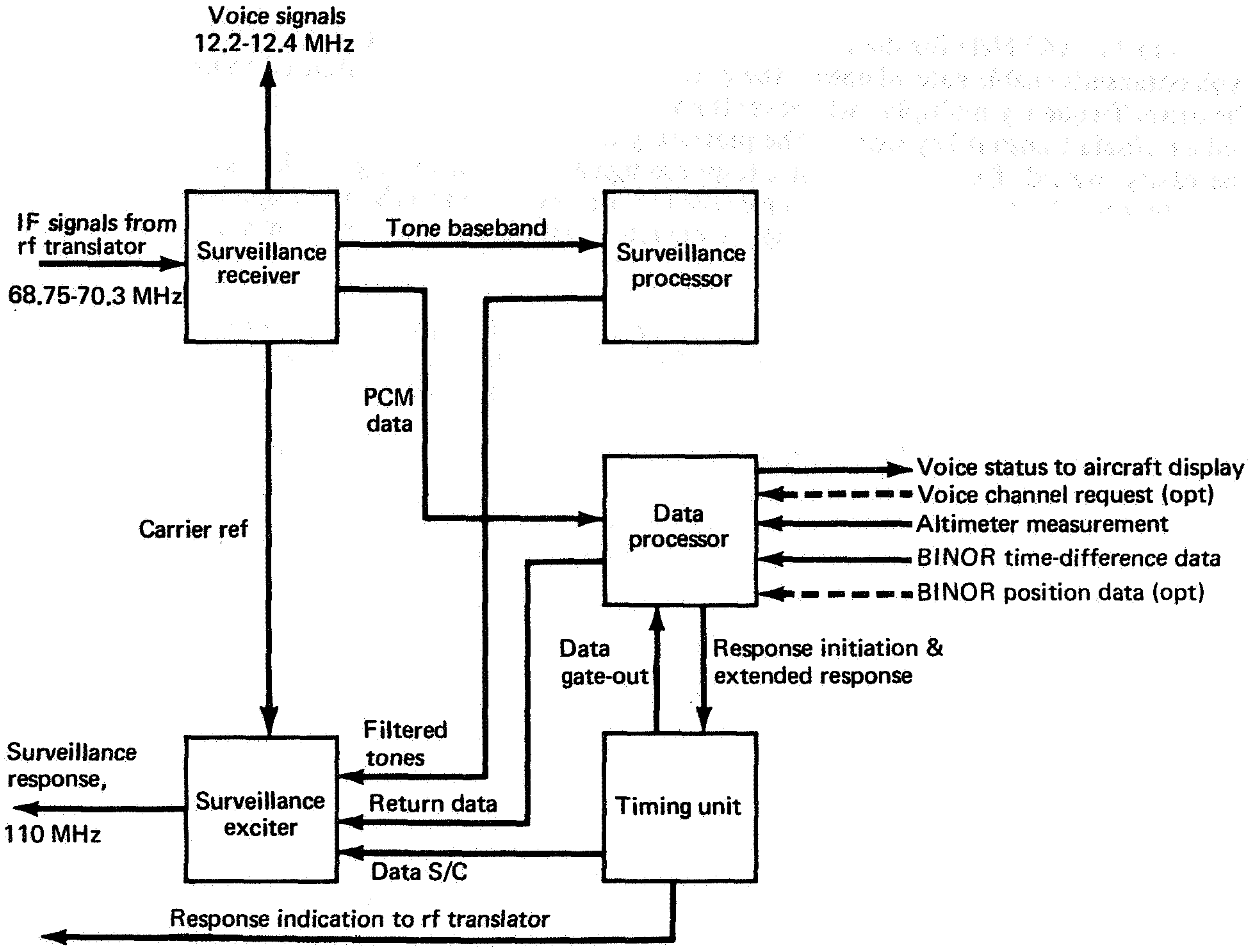

FIGURE 11.– SURVEILLANCE AND DATA SUBSYSTEM

band using a 82.5-MHz injection frequency derived from the VCO in the carrier tracking loop. The lower portion of the i.f. band, containing the voice channels, is then routed to the voice subsystems, and the surveillance signal is filtered out for coherent tracking. The surveillance bandpass filter passes a band including the surveillance carrier as well as all surveillance modulation. After further amplification and limiting, the carrier is then tracked in a phase-lock loop, with an automatic-sweep mode of acquisition initiated whenever out-of-lock indication is sensed by the search generator. The loop VCO frequency is also used for driving the rf translator mixers, the i.f. down-conversion mixer at the input of the receiver, and the carrier modulator in the surveillance exciter, so that the output carrier frequency is coherently related to that of the input for the surveillance response. The forward-link surveillance baseband is obtained from a second phase detector driven by a carrier reference from the carrier loop VCO. The baseband is sent to the surveillance processor where the five surveillance tones are filtered for subsequent turnaround transmission. The baseband is also presented to a subcarrier demodulator where the data subcarrier is filtered and demodulated. The demodulation is accomplished with a reference subcarrier generated from the incoming PSK-modulated subcarrier using a squaring loop in the bit synchronizer. The data and synchronization are then routed to the data processor for decommutation.

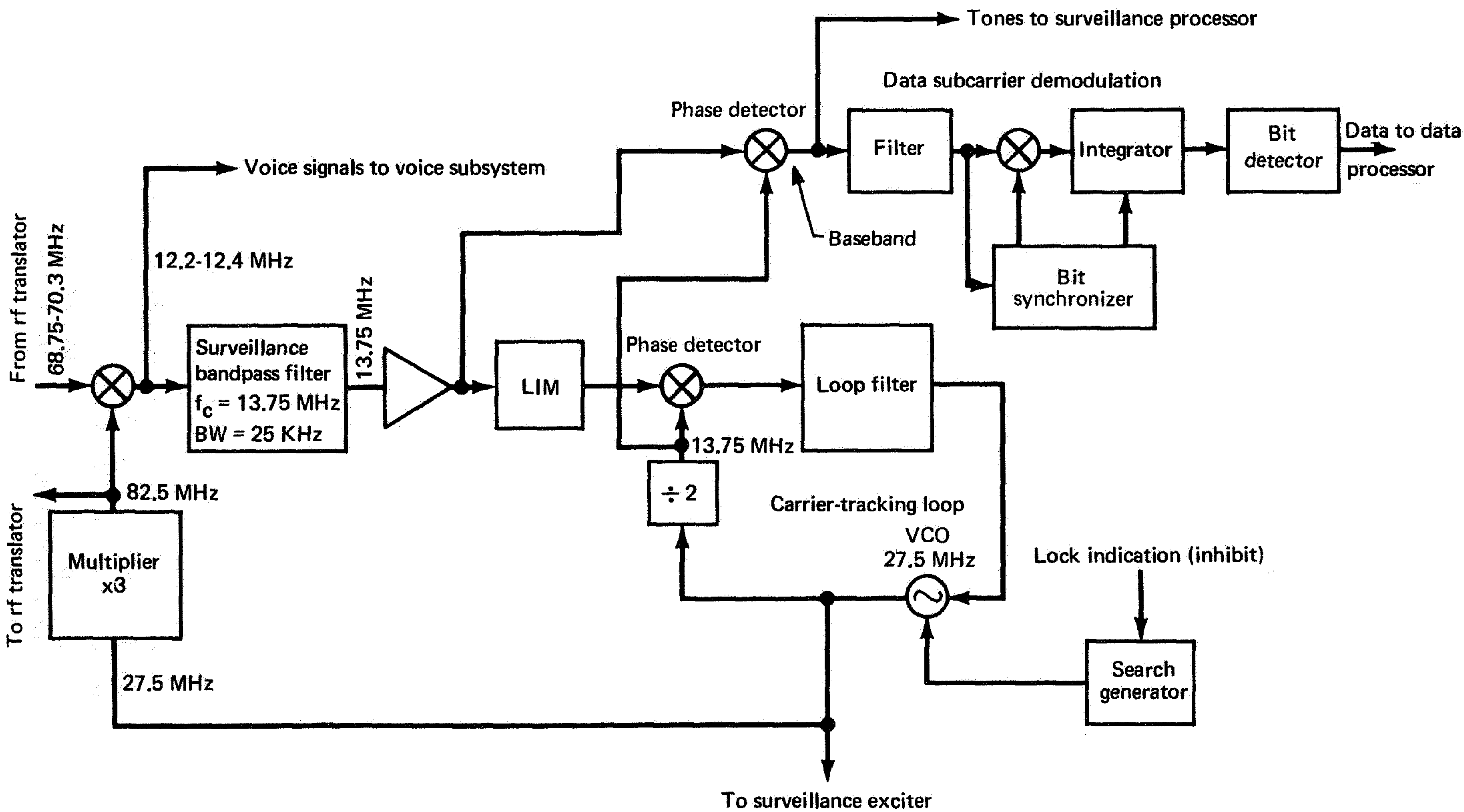

FIGURE 12.– SURVEILLANCE RECEIVER

3.3.1.2 Surveillance processor: The surveillance processor permits the turnaround transmission of the five received surveillance tones by providing filtering and conditioning prior to remodulation of the tones for the return surveillance response from the aircraft to the ATC. The five received tones are at frequencies of 8000 Hz, 9500 Hz, 9875 Hz, 9968.75 Hz, and 10 000 Hz, since different tones are used to transmit the tones in a cluster rather than at the original tone frequencies of from 31.25 Hz to 10 000 Hz. These tones are filtered by the surveillance processor in a single bandpass filter of 2400-Hz bandwidth with a center frequency at 9 kHz. The added bandwidth is provided to obtain flat response in the 8- to 10-kHz band. Since noise is also present with the tones, filtering permits the elimination of noise outside the passband so that excessive power is not consumed on the return link by transmission of unwanted noise. The filter design must minimize phase delay effects across the band so that excessive unknown phase errors are not added to the tones (which would result in an unrecoverable range measurement error). Frequency stability of the received tones is relatively high, since doppler effects are tracked out in the carrier loop. Only the instability of the filter, therefore, will contribute phase errors. These errors can be minimized (1) by providing filter adjustments which can be adjusted during testing to provide a specific delay through the filter, and (2) by using high-quality components and possibly environmental control to reduce phase-delay changes caused by the filter. The surveillance processor unit also conditions the filter output, providing to the exciter a specific output level to control the subsequent phase modulation of the tones upon the return carrier.

3.3.1.3 Data processor: The function of the data processor is the decommutation of the received data stream and the formatting of the return data channel for the aircraft response. The data processor is provided by the receiver with the synchronized data stream demodulated from the data subcarrier. The data stream is a recurring frame of 55 bits transmitted once per second. Each subsequent frame is updated with a new aircraft address code, extended response command, and voice channel status data, if applicable. The processor first obtains frame synchronization from detection of a 17-bit Legendre code. The remainder of the frame includes an aircraft address code (8 bits in length, transmitted three times), extended-response command (7 bits), and voice-channel status information (7 bits). The address code is compared in a 2/3-majority-voting comparator to a stored code unique to the aircraft, and when the specific aircraft code is received an actuation signal is provided to the timing unit which then initiates and sequences the aircraft surveillance response. This response is lengthened by detection of the extended response command, if present. The voice-channel status information received from the ground ATC center is converted to on-off signals indicating use or nonuse of the individual voice channels, with subsequent routing of the signals to the cockpit for visual display.

The data processor also formats the response message by accumulating in a storage register synchronization bits, a frame-synchronization code (17 bits), aircraft address (9 bits), an altimeter measurement (11 bits), and, possibly, a voice channel request (3 bits). The register is gated out sequentially to the exciter upon reception of an actuation signal from the timing unit.

3.3.1.4 Timing unit: The timing unit controls and sequences the aircraft surveillance response when the correct address code is received. The normal response sequence is 0.99 second in duration—slightly shorter than the 1-second surveillance cycle in order to provide overlap margin. The sequence is timed either by a self-contained oscillator of relatively coarse stability or by a clock reference inputted from elsewhere in the terminal. Sequence initiation is effected by actuation from a signal from the data processor upon detection of the unique aircraft address code. The timing unit then (1) gates out to the exciter the return

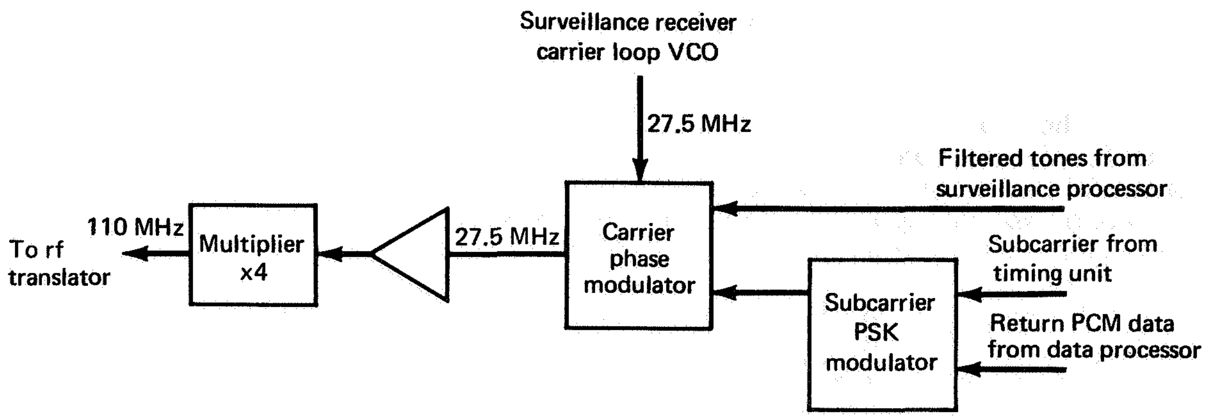

FIGURE 13.– SURVEILLANCE EXCITER

data frame from the storage register of the data processor, (2) provides a "key" signal to an AND gate in the rf translator and to the switching network, to indicate surveillance response, and (3) terminates the response after 0.99 second.

Should the actuation signal from the data processor be followed by a second signal indicating reception of the extended-response command, the timing sequence is then lengthened to several seconds (e.g. five) for the extended response. The gating of return data from the data processor is likewise extended, with additional synchronization bits read out prior to the information bits.

3.3.1.5 Surveillance exciter: The surveillance exciter, shown in the block diagram of fig. 13, performs the generation and modulation of the return surveillance carrier for the aircraft response to the surveillance interrogation. The carrier is obtained from the VCO frequency (27.5 MHz) of the receiver carrier tracking loop and is phase modulated by (1) the filtered tones from the surveillance processor and (2) the return data subcarrier, which is provided from the timing unit and then coherently PSK-modulated by the return data gated in from the data processor. The data is gated out only during the 1-second surveillance response so that, at other times, the carrier is phase modulated by the filtered tones and an unmodulated data subcarrier. Modulation levels are set by the input levels of the data and tone subcarriers, which are conditioned to provide optimum power division among the channels in the carrier modulation. After phase modulation of the carrier, the signal is amplified and multiplied times four to a frequency of 110 MHz for presentation to the rf translator of the rf subsystem. Gating of the 1-second response in the rf translator is performed with an AND gate keyed by a signal from the timing unit.

3.3.2 BINOR surveillance. – For operation with a BINOR surveillance scheme, the surveillance and data subsystem is comprised of four components: a receiver, data processor, timing unit, and exciter. The surveillance processor is excluded since no tones are now present for turnaround transmission. The operation of the four components used is as described previously for the tone scheme, but with slight modifications to the exciter and data processor. The exciter is altered to eliminate modulation of the tones on the return carrier, while the data processor is implemented to receive time-difference or position data from the BINOR subsystem for inclusion in the data frame for aircraft response.

3.4 Voice Subsystem

In the following discussion, the voice subsystem is described in terms of a block diagram with a brief functional description of each of the blocks. Portions of the voice receiver are functionally shared in the surveillance and data subsystem. In addition, the final stages of the voice transmitter are contained in the rf subsystem. The functional description of the voice subsystem can best be described by separating the discussion into the receive and transmit functions, since these two functions are independent.

3.4.1 Functional description of receiver. - The basic voice receiver (fig. 14) gets an input derived from the second mixer in the surveillance and data subsystem. The voice receiver consists of a third mixer/i.f. stage, a phase-locked demodulator (PLD) stage, and an audio section. The general requirements for those portions that precede the voice i.f. filter are discussed in Secs. 3.2 and 3.3. Therefore, for this discussion, consider the input to the voice subsystem as the signal applied to the voice i.f. filter. This signal has been doppler-corrected and aligned by the carrier tracking of the surveillance signal.

The output of the filter is amplified to provide isolation. The output is fed into a third variable mixer whose output is dependent on the choice of channel being used. This output, after having been limited and filtered, is then fed into a phase detector.

The phase detector (PD) is used as the error-sensitive device for tracking the incoming frequency-modulated signal in the PLD. The PD output is amplified, filtered, and then fed into the audio stage and at the same time used as an input control voltage for the voltage-controlled oscillator (VCO). It is appropriate to think of the PLD as a matched filter. With such a filter, the incoming signal is cross-correlated with a replica of the signal modulation, so that the coherent advantage of keeping detection bandwidth equal to modulation bandwidth is realized.

In the case of a high input C/N, it is relatively simple to describe the PLD performance functionally. The PD compares the instantaneous phase of the received signal with the locally generated replica of the modulated signal derived from the VCO. The output of the PD is an error voltage proportional to the phase difference between the input signal and the VCO signal. This error voltage after passing through the appropriate low-pass filter (LPF) is fed back as a control voltage to the input of the VCO. Therefore, the VCO is locked in phase with the incoming signal. Since the instantaneous frequency of the VCO is identical with the incoming signal, the control voltage of the VCO represents the demodulated output signal that is fed into the audio stage.

For the PLD to function properly as a frequency discriminator, (1) the VCO must be tunable over the rf bandwidth (13 kHz) and (2) the instantaneous phase error must remain small. Both modulation and noise errors will contribute to the phase error, and, since they are both random, the only measure of phase error which can be easily calculated is the rms phase error. Therefore, for a good replica of the modulating signal, the mean-square error should be kept below one-quarter radian.

The loop low-pass filter (LPF) output signal, which is fed into the audio stage, is not the best filtered replica of the voice signal; consequently, the PLD loop is followed by an audio LPF. The voice signal, after passing through the audio LPF, is amplified and then fed into the headset or speaker.

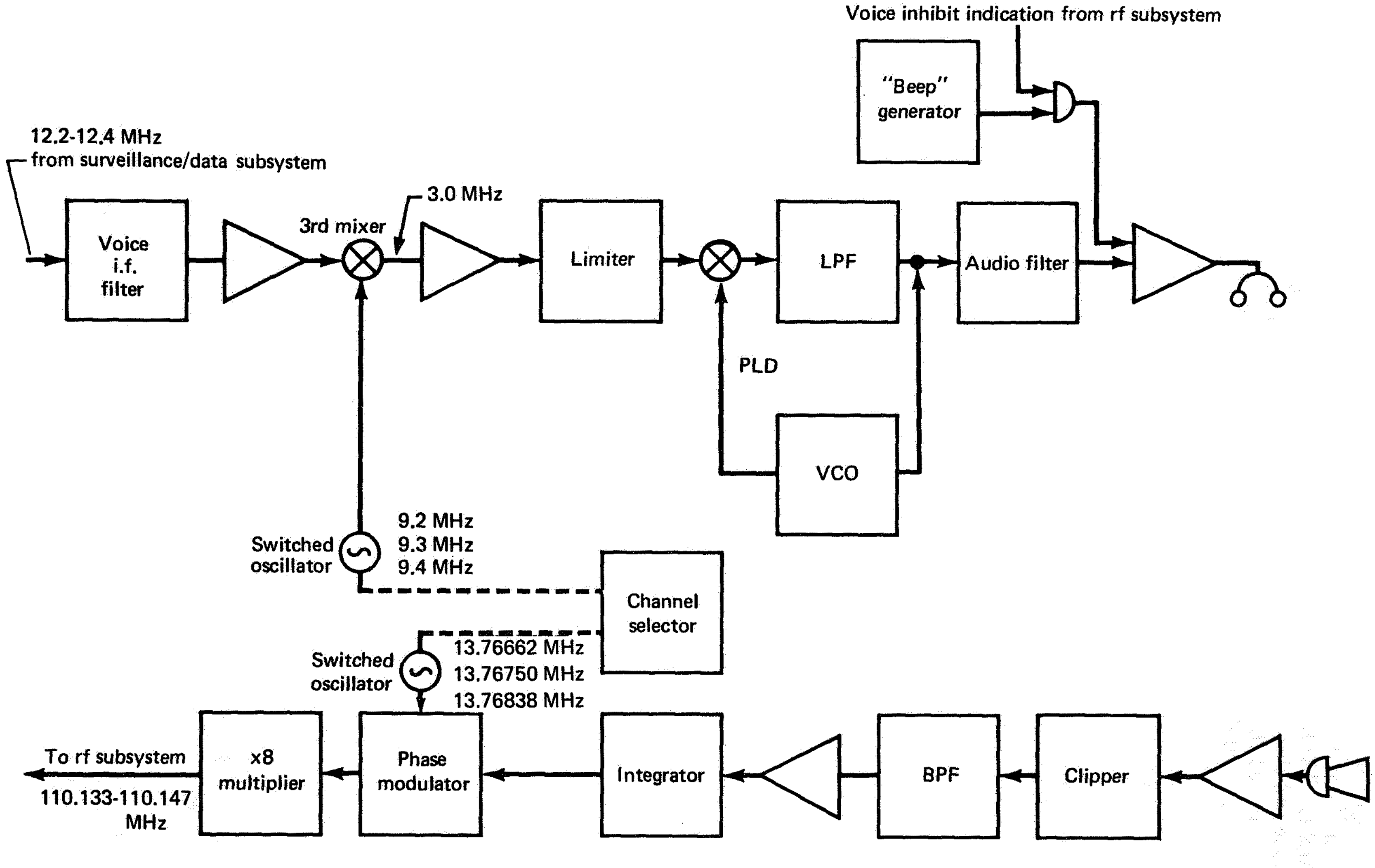

FIGURE 14.– VOICE SUBSYSTEM

3.4.2 Functional description of transmitter. - The basic voice transmitter is also shown in fig. 14 and consists of a clipper, filters, amplifiers, integrator, phase modulator, and frequency multiplier. The input to the transmitter is the aircraft operator's voice being fed into a microphone and then amplified. To insure the first amplifier's speech output is of the required level to feed the clipper, an automatic volume control (AVC) circuit is provided. The clipper is set such that the peak-to-rms level at the input to the modulator is equal to 6 dB. The output of the clipper is fed into a bandpass filter (BPF), which is used to remove most of the harmonics generated by the clipper and to attenuate speech frequencies above 3.2 kHz. The output of the BPF is then amplified to provide the proper level input to the modulator.

In a typical FM modulator suitable for voice transmission, the input signal to the modulator is first integrated and then used to phase-modulate a crystal-controlled carrier frequency. The carrier frequency is selected by the choice of channel used. To minimize the inherent distortion of a phase modulator, the maximum phase variation is kept small, resulting in a very narrowband FM signal. The output of the phase modulator is fed into the driver and then multiplied by the appropriate frequency multipliers to produce the desired FM deviation at the correct channel operating frequency.

Since the voice and surveillance/data subsystems use the same transmitter/power amplifier, the following additional circuit and indicators are provided. If the aircraft's interrogation address is received and a surveillance reply is initiated while the operator is talking, a "beep tone" is sent to the operator's headset, thus indicating (if he happens to be talking) that he was cut off briefly during the surveillance reply period ($<$ 1 second) and that he should repeat that portion of his transmission. In addition, a panel indicator light is actuated every time the aircraft's surveillance signal is received. This interruption is of short duration and occurs only once every 3 minutes. The combined effect of an indicating light and a talking rate of 2.5 words per second gives, as a result, low probability of message disruption.

3.5 Physical Characteristics

The following sections consider both the physical characteristics such as power, weight, and volume required for an experimental terminal as well as the terminal compatibility considerations such as antenna mounting and equipment installation.

3.5.1 Weight, volume, and power requirements. - Although weight, power, and volume are not major constraining factors for an experimental terminal, they are quite important in an operational system. The final selection of the operational components will be optimized in terms of maintainability, cost, weight, volume, and power. The information provided for the experimental terminal represents a first estimate for the necessary components. Typical weight, power, and volume requirements for an experimental flight-test aircraft terminal are given in table 13. The BINOR physical characteristics are taken from ref. 7 and include an optional Nortronics computer (NDC-1060). The total weight with the BINOR package is 181 pounds; without the BINOR package, which would not be required for tone ranging, the total weight is 122.5 pounds.

3.5.2 Installation compatibility constraints. - There are a few physical installation restraints imposed by the SST configuration and environment which must be carefully considered in the design of the L-band terminal.

TABLE 13.—PHYSICAL CHARACTERISTICS OF EXPERIMENTAL TERMINAL

	Weight, lb	Power, W	Volume, in^3
Transmitter	40	1650	1611
(Power amplifier, transmitter power supply, output filter, driver/multiplier, voice exciter)			
Receiver	25	50	1510
(RF section, voice receiver, surveillance/data receiver, surveillance processor, timing unit, data processor, surveillance exciter)			
BINOR package	58.5	200	2570
Preamplifiers	16.5	200	420
Diplexers	15	—	310
Feedline	9	—	—
Antennas	17	—	1840
Total	181.0	2100	8261

First, the antenna must be flush with the fuselage to be compatible with aerodynamic requirements, particularly at supersonic speed. At supersonic speeds, the antenna and its surface must withstand the high skin temperatures (500° F) caused by aerodynamic heating. The expected antenna environment is discussed more thoroughly in Sec. 2.0 of vol. IV. Basic to the design of the antenna is the structural integrity of the fuselage, which limits the extent of structural modification that can be done to accommodate the antenna installation. The antenna will be integrated with the airframe and will be fully compatible with the airframe without affecting primary structure.

The L-band terminal electronics packages must also be compatible with the aircraft configuration. Insofar as the experimental terminal installation is concerned, the power amplifier and other modem packages will probably be installed in a special flight-test electronics rack temporarily mounted in a convenient location in the SST passenger compartment (forward of the wing-root area and relatively close to the antenna). In this location, acoustical and vibration environments are not expected to be excessive and special precautions to protect the equipment will not be required. Cooling of the racked equipment can be readily accomplished with cabin air, according to ARINC-404 characteristics (ref. 8). It should be recognized that L-band terminal equipment for a production SST would be installed in an allocated electronics equipment compartment. While such a compartment would be pressurized and provided with cooling air, the chosen airplane configuration might impose severe acoustical and vibration environmental limitations upon the L-band equipment. Terminal equipment would necessarily have to be designed to withstand these conditions and conform to FAA technical environmental requirements in accordance with ref. 9. In addition, the possibility exists that packaging on the SST may not conform to ARINC 404 if an integrated avionics system is used. In an integrated system, some elements (such as a very stable frequency synthesizer) will be shared by all onboard communications and navigation systems requiring stable oscillators.

If long transmission lines are required between the electronics equipment compartment and the antenna, it may be necessary to locate the preamplifier for the operational L-band terminal near or integrated with the antenna, where it may be subjected to the temperature of the hot airplane skin. Thus, separate provisions must be made to cool this unit and maintain normal operating temperatures conducive to low failure rates and long operating life.

No other constraints are evident at this stage of terminal and airplane development.

3.6 Interface Compatibility

Subsystem interfaces exist among the following subsystems:

(1) RF subsystem

(2) Voice subsystem

(3) Surveillance and data subsystem

(4) BINOR subsystem (possible)

In order to insure that (1) a subsystem does not degrade the performance of another subsystem, and (2) the input signals from one subsystem to another subsystem are at the proper level, the following factors must be considered:

(1) Signal conditioning

(2) Isolation

(3) Grounding (subsystem tied to system ground)

(4) Shielding

(5) Thermal radiation

The exact specifications to ensure the proper signal conditioning, isolation, grounding, shielding, and thermal radiation will be developed in phase II of this program. Subsystem-interface circuit-data sheets, grounding-tree diagrams, etc., will also be included in phase II.

The L-band terminal also must interface with several airplane systems; namely, the onboard primary-power busses, the air data system, the interphone system, and the navigation system.

The primary-power busses provide 400-Hz,3-phase power at 208 volts ac as well as 27.5-volt dc power. The bus capacity is adequate to handle the nominal 2-kW power load of the L-band terminal. Direct current for solid-state modem power may be taken from one of several transformer/rectifier dc busses. However, dc required for the power amplifier is obtained from the amplifier's own power supply.

Compatible interface with the air data system is necessary to obtain airplane altitude data for surveillance. Altitude will be encoded in standard ATC beacon code per ICAO Annex 10 (ref. 10) for eventual automatic altitude reporting in the National Airspace System. It may be used in this form for the L-band terminal input.

An interphone tie-in, that switches microphones and headsets in various airplane positions into the communications system, probably will not be a requirement for the L-band experimental terminal. However, in an operational system this type of interface would be required in accordance with the provisions specified in ARINC Characteristic 566A for VHF Satcom Systems (ref. 11).

Inputs to the terminal data subsystem would require airplane-position data derived from the onboard inertial-navigation system (INS) if this data is desired for cross-correlation in evaluating the surveillance system. Signal conditioning may be required at this interface to ensure compatibility. This feature is not planned for the initial experimental terminal, but it could provide a growth potential of some significance.

Complete systems integration will be detailed in phase II of this program.

4.0 EXPERIMENTAL FLIGHT-TEST INSTRUMENTATION

Flight-test evaluation of the experimental SST L-band satcom terminal will require test instrumentation compatible with flight and environmental parameters of the test-bed aircraft. Interim terminal testing may also be accomplished on a subsonic test-bed aircraft. This section discusses the instrumentation required for flight testing of the experimental terminal (subsonic test bed or SST prototype) and some interim experiments that can be performed using the terminal implementation in a subsonic test-bed aircraft to determine the extent of L-band environmental radio noise and multipath propagation effects.

It is anticipated that initial flight testing of the L-band satcom system will occur in a rather austere program providing only one satellite with an L-band frequency-translation repeater. Complete evaluation of the system surveillance performance, which functionally requires at least two satellites for the cw tone ranging and possibly three for BINOR ranging, will not be possible at that time. Limited surveillance testing of the terminal using a single satellite is possible, however. This can be done by simulating the second and third satellites at ground positions, preferably at the ground control terminal that originates the ranging signal, and by flying the test-bed aircraft within line-of-sight propagation distance from that terminal. Figure 15 illustrates the system configuration for simulating two-satellite surveillance.

The discussion of flight-test configurations is based upon the following general assumptions:

(1) The second of the two planned SST prototype aircraft will be used as a test bed. The first is designated the "flutter" test airplane, whereas the second is for environmental testing, etc. Supersonic flights will be at instrumented Pacific Coast offshore flight-test corridors or at the Edwards inland flight-test corridor, whichever is ultimately chosen for SST flight testing. At subsonic speeds, flights would be over sections of these same corridors or over the Puget Basin (northwest Washington State) instrumented flight test corridor used by Boeing for subsonic flight testing. Over-sea-water flight corridors are desirable to assess fully multipath propagation affects.

(2) Using a subsonic test bed, such as a 707-type aircraft in flight-test status, the flights would similarly be over presently used instrumented flight-test corridors such as the Puget Basin.

(3) Other flight-test programs required for aircraft performance testing will undoubtedly be in progress during testing of the L-band terminal system. Consequently, the L-band system tests will have to be conducted simultaneously with and be fully integrated with the other tests to ensure efficient scheduling of the flight-test aircraft. All flight testing requires flight-test telemetry and communications directly to flight-test ground control terminals, thereby limiting flights to the instrumented test corridors assumed above.

(4) Evaluation of the experimental L-band terminal per se can be accomplished more easily over a "local" instrumented test corridor than over the North Atlantic air routes with the results being as adequate and significant.

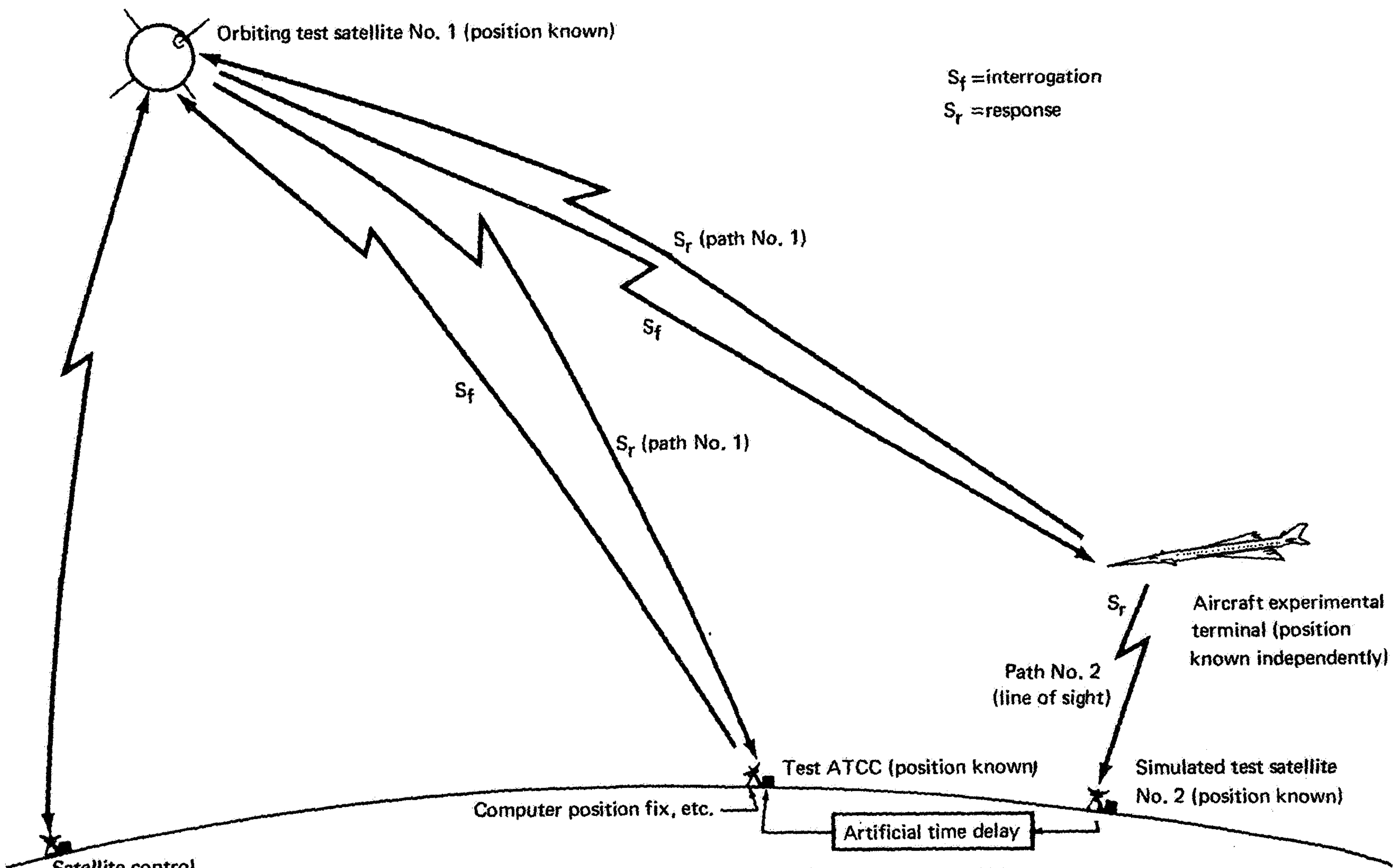

FIGURE 15.– SYSTEM SIMULATOR–CW TONE RANGING

(5) To be compatible with the probable supersonic and subsonic flight test corridors used by the test-bed aircraft, the one satellite (with L-band translation capability) used for the experimental terminal tests can be positioned over the equator in geostationary orbit between longitudes 90° W and 150° W. If the ATS-F satellite is designated to carry an L-band translator, other experiments on board the satellite might require a different satellite position. However, neither the type of experiments nor the optimum satellite positions can be anticipated now. NASA undoubtedly would consider all experimental requirements and program the satellite adequately to accommodate them all.

(6) No special test-bed aircraft L-band antenna is required for the radio path between aircraft-to-simulated-satellite ground terminals because the shorter path length (<350 n.mi.) has at least 36-dB less loss than the actual aircraft-to-satellite path, ensuring adequate signals at the ground from the aircraft satcom antenna back/side lobes.

(7) During test flights, there is a possibility that the air-to-ground flight-test telemetry link transmitter (probably using the presently assigned frequencies of 1445.5 and 1465.5 MHz) can cause interference in the adjacent L-band satcom receive channel (1540 MHz). The telemetry transmitter will have 20 to 100 watts of power with either PCM/FM or PCM/FSK modulation. This possible interference will be reduced to a tolerable level or eliminated by adequate EMC treatment.

4.1 Measured Quantities

It is anticipated that test-bed instrumentation will be required to measure, correlate, and display (onboard) a number of pertinent aircraft flight parameters and aircraft environmental parameters in addition to the L-band satcom system surveillance and communications parameters required to evaluate the L-band terminal. It may also be necessary to telemeter all, or part, of these to a flight test center on the ground for additional monitoring or data processing.

4.1.1 Aircraft flight parameters. – Aircraft flight parameters needed to correlate with L-band system measured parameters to assess properly L-band system performance are:

(1) Altitude

(2) True air speed (TAS)

(3) Pitch (angle)

(4) Roll (angle)

(5) Yaw (angle)

(6) Heading (true/magnetic)

(7) Real-time reference

(8) Latitude

(9) Longitude

(10) Ground speed

During all test flights of Boeing aircraft on flight-test status, the above parameters are among those measured by the normal flight-test instrumentation carried aboard the aircraft. The parameters are recorded and displayed aboard the aircraft and are digitized into PCM telemetry format for transmission to the flight-test control center on the ground where the parameters are again recorded and displayed. The analog-to-digital converter in the PCM system provides 10-bit accuracy. Of the 1000 data channels available in this system, 100 to 200 channels are used for prime data (depending upon the particular flight); the remaining channels are available for other data if needed. Fourteen data tracks are recorded onboard; each track has 45 channels, two of which are reserved for frame synchronization, which leaves 43 channels for data. The 13th track is reserved for time reference and is synchronized daily with WWV standard-time transmissions to provide 10^{-6} clock accuracy.

4.1.2 Environmental parameters. – Salient environmental parameters needed to correlate with L-band system measured parameters to assess adequately the L-band terminal performance are:

(1) Antenna-area skin temperature

(2) Transmission-line and preamplifier temperature

(3) Sea state (at signal reflection area)

(4) Radio refractivity profile (along signal paths)

(5) Ionospheric profile (along paths to satellite)

4.1.2.1 Temperature: The test-bed SST aircraft should be instrumented with special sensors to measure skin temperature specifically at the L-band antenna and to measure the antenna element and feed temperatures, because these have a significant bearing on antenna performance at supersonic speeds. At subsonic speeds, these parameters have less significance but should probably be measured to provide information on all possible sources of anomalous terminal behavior should it occur during tests. Also at supersonic speeds, the terminal preamplifier and transmission line from the antenna may be located close to the antenna terminals, possibly in an area between the fuselage inner and outer skins, wherein temperatures will be high due to conduction and radiation from skin aerodynamic heating. Instrumentation to monitor continuously these component temperatures can be integrated into normal flight-test parameter instrumentation.

4.1.2.2 Sea state: Signal fading margins due to multipath reflections from the sea surface are largely controlled by the sea-state conditions at the reflection area. The sea state can vary considerably, depending upon both regional and local meteorological patterns. Along the west coasts of Oregon and Washington, both well-developed "seas" and swell conditions usually exist nearly into shore, because of onshore winds and a narrow continental shelf. Conversely, on the Atlantic Coast of the United States, the 15°F to 20°F warmer water prevailing offshore, surface wind patterns, and the wide, shallow continental shelf keep the sea surface relatively calm 50 miles or more from the shore, except during hurricanes.

In general, along the West Coast, southwest winds prevail during winter, causing sea swells that are developed hundreds of miles off shore to move continually into shore. Between June and September, northwest winds prevail and the Coriolis effect moves ocean-surface water westward offshore causing upwelling of cold lower-level water, creating summer fogs. In September, wind speeds slow down, and the northwest winds mix with occasional northeast winds flowing through the Strait of Juan de Fuca (northwest Washington State), calming the sea offshore, and dispersing the fog. These varietal sea conditions near shore make the Oregon and Washington coast very suitable for measuring multipath propagation effects during flight testing. In addition, updated sea–state conditions are available hourly via the U.S. Weather Bureau HF broadcasts or direct via HF radio circuits from USCG lightships Umatilla, Columbia River, and Blunt's Reef located about 20 miles offshore spaced between Umatilla Reef (northwest Washington State) and Cape Mendicino (northern California).

4.1.2.3 Radio refractivity profile: Data on the radio refractivity profile are probably useful only in the experimental flight tests, because simulated satellite implementation on the ground requires aircraft-to-ground signal paths traversing considerable amounts of the lower troposphere, especially at small grazing angles. Availability of these data will permit correlation with system parameters to help explain occasional discrepancies that may occur in signal levels, position fix accuracies, and data error rates.

Average radio refractivity profiles for flight-test signal paths can be derived from synoptic data readily available in technical literature (ref. 12). Current diurnal data for these paths can be obtained by arrangement with existing meteorological stations in the general vicinity of the flight-test range – Tatoosh Island, Washington; Medford, Oregon; Oakland, California; Ship Station N (140°W, 20°N); and Ship Station P (145°W, 55°N)– which take radiosonde readings periodically each day. If finer-grained data are required, it may be necessary to arrange for radiosonde soundings directly in the signal path through the troposphere.

4.1.2.4 Ionospheric profile: Reasonably good ionospheric profile data along the signal path where it penetrates the ionosphere (to and from the satellite) may be best obtained from an oblique incident ionospheric sounder operating during test periods. Access to a sounder within view of the probable ionospheric penetration region is ensured, because a sounder is operated by the Washington State University at Pullman, Washington, which is about 340 miles inland from the southwestern Washington coast. Refinement of the oblique-sounder data possibly may be made, if necessary, from Alouette topside-sounder data obtained through the U. S. Department of Commerce/Environmental Science Service Administration (ESSA) at Boulder, Colorado. Ionospheric profiles may help correlate possible propagation phenomena with any discrepancies in test signal levels and position fix accuracies.

4.1.3 L-band system parameters. – The L-band system parameters requiring measurement to assess system performance can be categorized according to system operational mode: surveillance or communications. While operationally the user terminal surveillance modem will be in a transponder configuration, during experimental tests it will be expedient to measure terminal performance aboard the aircraft as well as at a ground terminal.

4.1.3.1 Surveillance test parameters: Required surveillance parameters common to both cw tone ranging and TRW's BINOR concept are:

(1) Received carrier level (dBW) versus time

(2) Received carrier-to-noise ratio (C/N, dB)

(3) Power amplifier output power (dBW)

(4) Antenna VSWR

(5) Received frequency

(6) Transmitter frequency

(7) Carrier acquisition time

(8) Receiver-loop acquisition bandwidth

(9) Received-carrier doppler rate and shift

(10) Bit error rate

(11) Demodulator synchronization loop acquisition time

(12) Data-channel frame and bit acquisition times

In addition, the cw tone ranging configuration requires:

(1) Tone-channel individual tone/noise ratio in the turnaround tone bandwidth

Additional parameters required for the BINOR configuration are:

(1) Clock-loop acquisition time

(2) Receiver-loop lock stability during mode switching (acquisition/tracking)

Recording of the above parameters will facilitate evaluation of:

(1) Received carrier acquisition probability

(2) Carrier tracking properties

(3) Code acquisition properties

(4) Data acquisition and accuracy properties

(5) Receiver phase accuracy properties

4.1.3.2 Voice communications test parameters: Required voice communications parameters are:

(1) Received carrier-to-noise ratio (C/N, dB)

(2) S/(S + N) (output)

(3) Received carrier level (dBW)

(4) Carrier acquisition time

(5) Cockpit acoustic noise level

(6) Speech intensity level

(7) Power-amplifier output power (dBW)

(8) Antenna VSWR

(9) Channel intermodulation levels

Recording of these parameters will facilitate evaluation and analysis of:

(1) Carrier tracking properties

(2) Percent word intelligibility/articulation index

(3) Communications reliability

(4) Channel threshold effects

(5) Multiple-access degradation

4.2 Recording and Data-Reduction Methods

The data recording and reduction methods and instrumentation for L-band experimental terminal evaluation are expected to be straightforward. Provisions will be included in the experimental flight-test instrumentation to permit a quick-look capability to confirm terminal operational integrity as testing progresses and to validate the various data measurements.

Both multichannel chart recordings and FM tape recording subsystems will be utilized to provide data for immediate observation and later analysis. The tape recordings may be used directly with automatic digital data-processing techniques.

4.3 Recommended Interim Experiments

Before full implementation of an experimental airborne L-band satcom terminal for flight-test evaluation, two classes of interim experiments can and should be made. The first is the measurement of ambient L-band radio noise temperatures onboard an aircraft to obtain significant low-noise-level data previously unavailable and to pinpoint possible problem areas from typical onboard interference sources. The second is the detailed measurement of L-band multipath propagation characteristics to substantiate the analytical results of Sec. 6.0, vol. III, of this report.

To delineate the interim experiments, it is assumed that they will be conducted prior to the orbiting of an L-band satellite and the flight testing of SST prototypes, i.e. during 1969 and 1970. Consequently, the experiments will be configured to utilize ground-based implementation where practical and subsonic airborne platforms where needed. Also, instrumentation components whenever possible will be selected from commercially available units so that they can be utilized later in the implementation of the experimental airborne L-band terminal.

4.3.1 Radio noise experiments. - The following descriptions suggest interim radio-noise experiments that are desired to expand or confirm estimates of certain noise temperature levels used in Sec. 7.0, vol. III, for the noise analysis.

4.3.1.1 Self-generated radio noise: Prior to flight tests of the L-band experimental terminal aboard the prototype SST, it should be feasible to measure noise at 1500 to 1700 MHz aboard a subsonic jet with equipment having sensitivity equal to that of the experimental terminal. During flights, the ambient radio noise level could be measured continuously, noting how it is affected by switching and operating conditions of all onboard electrical and radio/electronic systems, singly or in combination. These conditions could also be preflight-checked on the ground. To prevent masking of the onboard noise level, this would have to be done at a ground location having an extremely quiet local ambient noise level.

4.3.1.2 Static-discharger radio noise: While the purpose of orthogonal null-field static dischargers normally installed on jet aircraft is to prevent radio noise due to corona buildup from triboelectric charging of the airframe, there has been some indications (especially at VHF) that the discharge currents can generate radio noise. A laboratory experiment is suggested in which orthogonal null-field dischargers are mounted on a mockup airfoil simulating the geometry of a corona-susceptible aircraft extremity. The mockup is then electrically charged to values that produce discharging of the null-field devices. During the discharge process, the radio-noise spectrum is measured on sensitive radio-noise-measuring equipment located adjacent to the mockup. This should provide data indicative of the discharger noise level, if any, at 1500 to 1700 MHz.

4.3.1.3 Sferic radio noise: It was recommended in Sec. 7.0, vol. III, that the estimated level of 1500- to 1700-MHz radio noise generated by nearby sferics be experimentally confirmed. It is probably more practical to accomplish this at a ground terminal rather than at an airborne terminal. The ground terminal could be located geographically in a typical thunderstorm area (such as Oklahoma, northeastern Colorado, or even northeastern Washington/Idaho) where sufficient lightning activity is available to provide adequate data in a reasonably short time. Suitable noise-measuring equipment is shown in the block diagram, fig. 16. The receiver will be calibrated to provide measurement of the peak power density at 1500 to 1700 MHz of specific identifiable sferics as a function of distance. The distances from the receiving equipment to individual lightning strokes of interest can be obtained from a knowledge of the terrain and by visual and aural observations by a number of observers strategically placed around the thunderstorm area, providing a coarse trilateration using compass directions and time delay between the lightning flash and the corresponding thunder clap. If greater accuracy is necessary, special electronic sferic direction-finding receivers may be used (refs. 13 and 14).

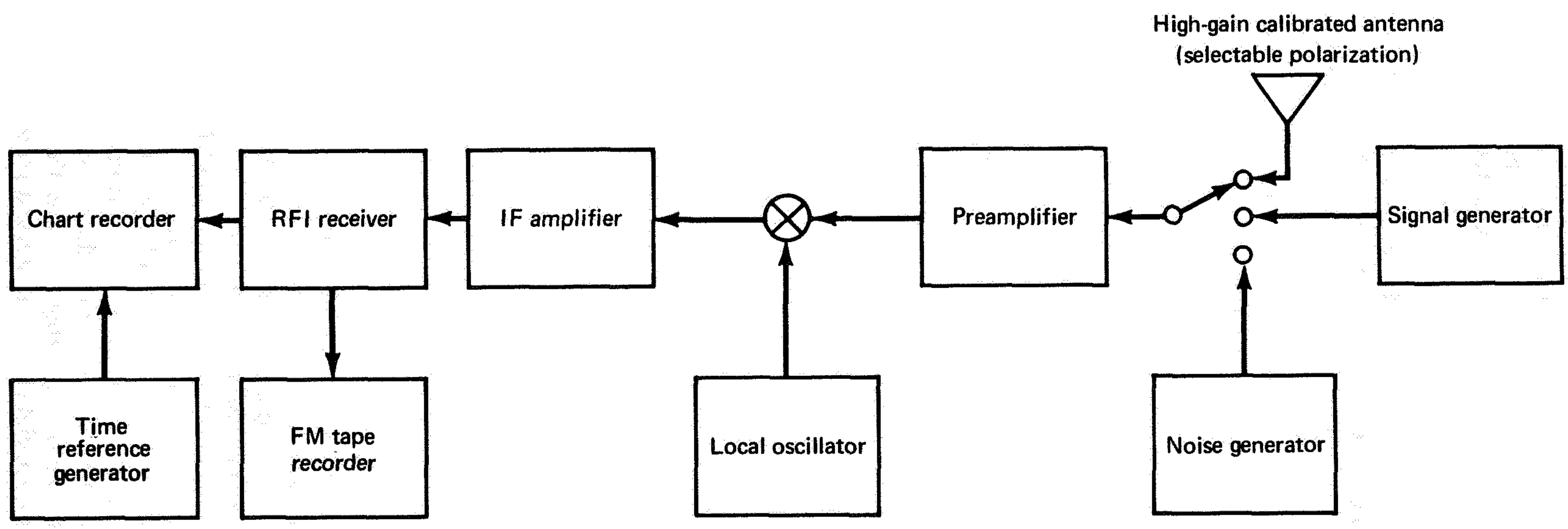

FIGURE 16.– TEST SETUP BLOCK DIAGRAM FOR INTERIM NOISE EXPERIMENTS

4.3.2 Multipath experiment. - A cursory examination of the geographical-location criteria required for a ground-based experiment that measures multipath parameters to confirm further the validity of the multipath analysis used in this study shows that no suitable natural geometry over sea water can be found in the Oregon/Washington coastal or inland waterways. Indeed none may exist within accessible regions anywhere, because open rough sea water between two 270-foot sheer cliffs having 0.17 to 1.2 miles separation would be needed to accommodate adequately multipath measurements at grazing angles between 5° and 30°, the angles of principal concern. It appears then that a suitable experiment can be configured locally only by utilizing an aircraft for one terminal and a high, steep cliff overlooking the sea for the other terminal. Such a cliff (600 feet) is available adjacent to U.S. Highway 101 near Nehalem, Oregon (65 miles west of Portland). The geometry for an aircraft flying at a 12 000-foot altitude between 27.5 and 4.14 miles offshore would give grazing angles between 5° and 30°, respectively, and the reflecting points on the ocean surface would be 6930 feet and 1040 feet, respectively, from the cliff base. The geography of this configuration is such that the sea and swell development of the ocean extends well into the reflecting area, and the sea state at the reflecting area can be well defined because of the area's proximity to the Columbia River lightship that reports hourly sea-surface conditions. In this geometry, the aircraft terminal could fly radials from the ground terminal toward the open sea (and/or a return radial toward the ground terminal). As an alternate to or as an addition to that type profile, the aircraft terminal could fly constant-radius arcs at a selected distance from the ground terminal to obtain measurements of several minutes' duration during which the grazing angle remains constant. Thus, interference fringing due to aircraft motion toward or away from the ground terminal would not be superimposed upon the multipath data.

The geometry of the foregoing configuration is similar to that reported in Rider's multipath experiment (ref. 15), except that his configuration is limited to grazing angles below 3.5° with the reflecting area being beyond 3280 feet from the cliff base. Had he considered 30° grazing angles with his geometry, the reflecting area would have been only 70 feet from the beach, which is too close for valid results. Also, Rider did not have available quality sea-state data. Since his experimental results were in acceptable agreement with theory, the similar experiment suggested herein for larger grazing angles at an L-band frequency and using high-quality sea-state data should provide significant data with which to substantiate analytical results.

A simplified block diagram of the test instrumentation for this experiment is given in fig. 17. The high-gain fan-beam antennas at the shore receiving site will provide vertical-plane discrimination to separate the direct and reflected signals, especially at the larger grazing angles. This will permit study of the component characteristics. In addition, the composite signal will be measured and analyzed for statistical peak-to-trough fading parameters, particularly the power spectral density and the amplitude probability distribution.

The airborne transmitting antennas will have general coverage downward to ensure full illumination of the sea and direct signal path. Receiving-system calibration will be accomplished with the signal and noise generators at the receiver signal input. Experiment details will be postulated at a later date; the general procedures and techniques are familiar because they are similar to VHF multipath investigations Boeing conducted earlier.

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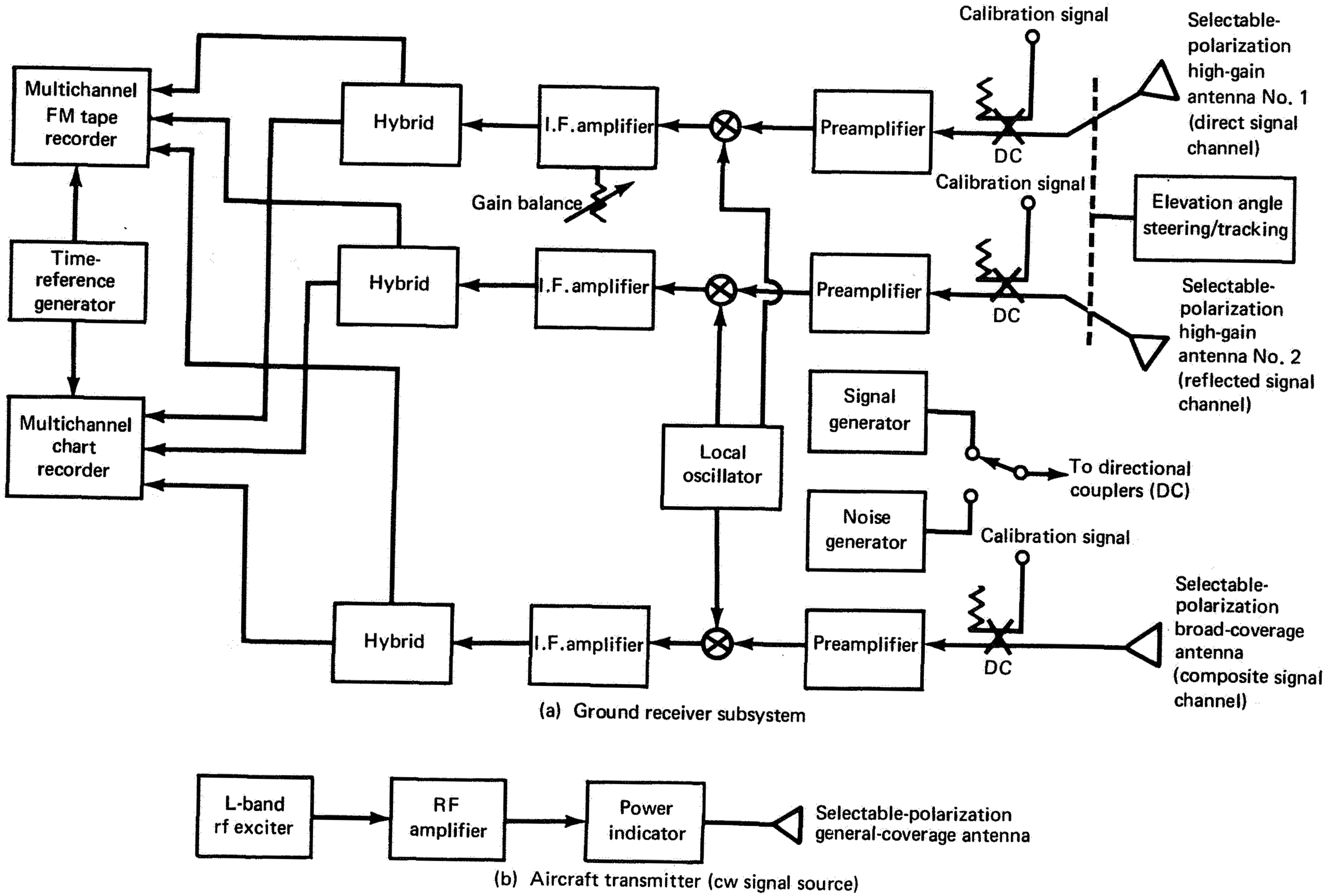

Note: Radio voice link (coordination) not shown

FIGURE 17.– INSTRUMENTATION BLOCK DIAGRAM FOR INTERIM L-BAND MULTIPATH TEST

5.0 GROWTH TO AN OPERATIONAL TERMINAL

The expected characteristics of the aircraft terminal to be used with the operational satellite ATC system are discussed in this section. The aircraft terminal developed previously for the experimental program would be modified for operational usage. The reasons for the modifications stem both from the expected change in satellite capability and the somewhat different goals of the experimental and operational programs. The design goal of the experimental terminal is to provide maximum test flexibility during the demonstration program. The design goal of the operational terminal must be to provide a cost-effective, minimum-complexity aircraft terminal amenable to integration into the airlines' fleet inventory.

5.1 Expected Operational Satellite Characteristics

In developing the required rf parameters for the experimental terminal program, it was recognized that the satellite available for the tests would not have as high an EIRP as the one developed for an operational system. For example, if the demonstration program is accomplished with the ATS-series satellites, then the L-band tests would be just one of several experiments. The resultant satellite design would thus be a compromise to satisfy the particular requirements of each experiment so that its capability represents the state of the art for an earlier time period (1972) than that of the operational system (1975-1980). In addition, the tradeoff of satellite and aircraft performance to obtain a minimum-cost system must be treated differently in the experimental and operational programs.

In the experimental program, there will be one satellite and a few aircraft terminals (possibly only the one on the prototype SST). Thus, it is more cost effective to put emphasis on developing the performance capability and associated complexity of the aircraft terminal than that of the satellite terminal. The additional dollar-per-pound cost of developing and orbiting the added satellite performance capability is thereby avoided. In the operational system, the cost tradeoff is significantly changed, since the system then consists of a few satellites and possibly several hundred aircraft-terminal installations. Although the overall system cost study has not been done, it is intuitive that there should be a shift in emphasis that would place increased performance capability and complexity into the operational satellite. The results of such a design approach should minimize the overall system costs and give the airline carriers a terminal design of reasonable cost and a minimum amount of operational and maintenance complexity.

It is therefore assumed that the operational ATC satellite system must provide a capability to permit the aircraft terminal to operate surveillance and voice channels through a low-gain, fixed-beam antenna system. The results of the antenna tradeoff analysis of Sec. 9.2, vol. IV, show than a candidate aircraft antenna system would be two low-gain antennas each mounted 30° off the top centerline of the fuselage. One antenna is selected for a particular flight by means of a simple left-right switch. Each antenna would provide a minimum gain capability of +3 dB at a 10° elevation angle. (There is a 2-dB increase in the required fade margin due to the reduced antenna multipath discrimination when the antenna is displaced 30° from top center.)

The previous link analysis was scaled for the +3 dB aircraft antenna gain and increased fade margin to develop the corresponding required satellite EIRP. The results show that a satellite EIRP of +47.6 dBW is required to support three voice channels and the forward and return surveillance links. If the satellite transmitter is assumed limited to 75 watts in the operational time period, the satellite antenna gain must be +30.4 dB to meet the EIRP requirement. Such an antenna would have a half-power bandwidth (HPBW) of 4.7° and would illuminate an earth surface area of about 2000 n.mi. A better approach to satellite design is use of a phased-array antenna, such as the Boeing APPA concept, of multiple simultaneous steerable beams wherein the power amplifiers are low-power devices integrated with the array elements.

5.2 Operational Aircraft Terminal Characteristics

A conceptual operational-terminal design, shown in fig. 18, is compatible with the satellite characteristics of the previous section. Forward-link ATC voice and surveillance signals are received from the satellite through the selected low-gain antenna. The performance parameters permit use of an economical transistor preamplifier and a 50-watt power amplifier. The latter may well be a solid-state device based on 1975 technology. As the block diagram shows, the system is quite similar to the experimental terminal design. The received surveillance and data carrier is continuously tracked and used for coherent frequency reference for the reply surveillance signal. It also provides doppler correction to the input voice carrier signal to aid in optimizing the voice channel demodulation. The forward-link data subcarrier is continuously demodulated to provide output data to all aircraft. This data permits updating the voice-channel status display to show the pilot which channels are currently in use. In addition, growth capability is provided to handle an expanded digital data link that would be useful in implementing an automatic flight management (AFM) system. The address in each cycle of the surveillance signal is checked in the address detector. When the unique address for an aircraft is detected, the surveillance reply link to the ATC is activated for 1 second. The reply data includes the surveillance signal, either turnaround tones or the position information associated with the processed BINOR signal, and a data channel. The data channel includes, as a minimum, aircraft identification and altitude data. Growth capability is also provided for return of both AFM-type data and pilot-inserted data.

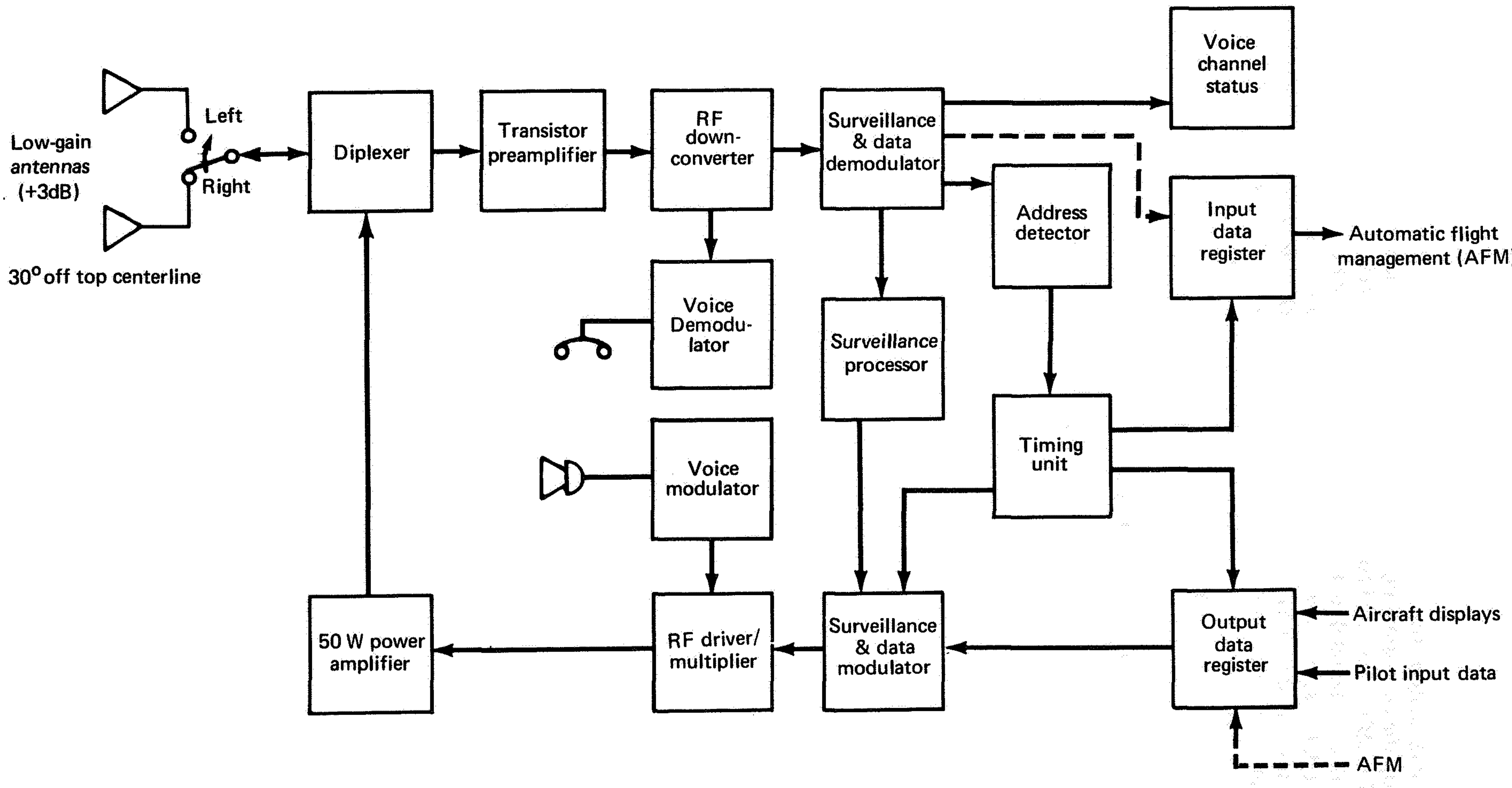

FIGURE 18.– CONCEPTUAL OPERATIONAL AIRCRAFT L-BAND TERMINAL

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